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PART XI 11

PROCEEDINGS OF SECTION K

THE CORRELATION OF CONTINENTAL VERTEBRATE-BEARING ROCKS

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PART XI

PROCEEDINGS OF SECTION K

THE CORRELATION OF CONTINENTAL VERTEBRATE-BEARING ROCKS

Edited by
W. E. SWINTON

LONDON
1951

Section K, The Correlation of Continental Vertebrate-bearing Rocks, met on three occasions during the Session, on August 25th, 28th, and 31st. Professor D. M. S. Watson was the Chairman throughout. Dr. W. E. Swinton was Secretary of the Section.

The meeting on August 28th was held jointly with Section H.

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*These papers were presented at the joint meeting with Section H, The Pliocene-Pleistocene Boundary. See also Part IX of the Report, which contains the proceedings of Section H.

THE VERTEBRATE-BEARING STRATA OF SCOTLAND*

By T. S. WESTOLL

Great Britain

ABSTRACT

Range of important faunas; Silurian to late Triassic age.

(1) The "Downtonian fish-bed" of Lesmahagow and the Pentlands is earlier than Downtonian, though probably not so early as Llandovery-Valentian. The Cowie Harbour fish-bed is truly Downtonian.

(2) Upper Downtonian faunas are unknown; the main fossiliferous horizons of the "Lower Old Red" are Dittonian.

(3) Possible Lower O.R.S. (without known vertebrates) unconformably underlies the true Middle Old Red of the Highlands in several places.

(4) The Old Red—Carboniferous boundary is arbitrary. The lower Calciferous Sandstone series may be equivalent to the *Remigolepis*-zone and higher beds in Greenland.

(5) The earliest Scottish Tetrapoda are Lepospondyli (s.l.) of Middle and late Viséan age (S_2-D_1). Many so-called "Lower Carboniferous" forms are Namurian.

(6) The vertebrate faunas of the Productive Coal Measures are Westphalian A-B. The Barren Red Measures have yielded no vertebrates.

(7) The age-determination of the Permo-Triassic vertebrates of the Elgin district requires some revision.

Much further work on the non-vertebrate fossils, sedimentation-conditions and facies-differentiation is required.

I. INTRODUCTION

IMPORTANT vertebrate faunas have been found in Scotland in Silurian, Devonian (Old Red Sandstone), Carboniferous, Permian (?), and Triassic rocks. They have been described and discussed by a remarkable succession of palaeontologists—from Valenciennes, Agassiz, and Pander, to Powrie, Hugh Miller, Huxley, Owen, Newton, Traquair, and Smith Woodward. More recently, von Huene, Watson, Stensiö, White, and many others are the heirs of a great tradition. Inevitably, much of the earlier work calls for revision, and one of the most important requirements is a new assessment of the stratigraphy of the deposits. This brief paper can do no more than indicate some of the implications of recent work and define certain new problems.

It should be remembered that many records of fishes (in particular) are based on fragmentary remains. Much new collecting is required before certain problems can be settled; but unfortunately the centralization of lime-kilns, the development of synthetic building-stones, the comparative rarity of new shaft-sinkings and changes in methods in the coal- and ironstone-fields, and the decay of other quarrying and mining activities (Caithness flagstones, oil-shales, etc.) have closed many of the most favourable localities. Equally bad is the present dearth of enthusiastic amateur workers. Opportunities for large-scale work on new material are now comparatively rare.

The writer has added to the paper, as originally submitted, by taking into account works published in Germany which were not earlier available. He also acknowledges, with thanks, discussions with Dr. J. Shirley on the Siluro-Devonian boundary problem; their conclusions are mutually confirmatory.

II. SILURIAN AND "DOWNTONIAN"

"Fishes" have been found in inliers of Silurian and so-called "Downtonian" in the Midland Valley; those of Lesmahagow and the Hagshaw Hills (Lanarkshire-Ayrshire) and the Lyne Water-North

*For discussion following the presentation of this and other papers, see p. 26.

Esk district in the Pentland Hills are discussed by Traquair (1899c, 1905), and the stratigraphy is summarized by Peach and Horne (1899). The Downtonian of Stonehaven was recognized as such by R. Campbell (1913, refs.) and the fauna has recently received much attention.

In the Lanarkshire inliers Peach and Horne (1899) recognize 11 stratal divisions, of which the lowest (1) is regarded as " Wenlock? ", numbers 2–6 as " Ludlow," and numbers 7–11 as " Downtonian." Above a possible disconformity is the Lower O.R.S., with a basal conglomerate (" greywacke-conglomerate "), a group of chocolate-coloured sandstones with *Cephalaspis lyelli*, and a higher volcanic group. Of the Silurian succession the most significant are numbers 3 (*Ceratiocaris* beds, including " Ludlow fish-bed "), 4 (*Pterygotus* beds), 7 (a local conglomerate in the Hagshaw Hills), 9 (red and green mudstones, etc., with the " Downtonian " fish-bed), and 10 (the " Quartzite-conglomerate ").

Zone 3 yields *Thelodus scoticus*, *T. planus* and *Birkenia elegans*; zone 9 is more richly fossiliferous, with *Thelodus scoticus*, *Lanarkia* spp., *Lasanius problematicus*, *Birkenia elegans* and *Ateleaspis tessellata.* In the Slot Burn, near Seggholm, there are two fish-beds in zone 9. The remarkable *Jamoytius kerwoodi* (White, 1946b) is from either zone 3 or 4.

In the Lyne Burn-North Esk inlier the strata are considerably obscured and faulted. The Gutterford Burn exposes strata called " Wenlock " by Peach and Horne (1899), which are probably older than strata, in the North Esk and its tributaries, regarded as " Ludlow." These are succeeded by yellow and red sandstones, grits and shales mapped as " Downtonian," which in the Lyne Water have yielded *Birkenia elegans, Lasanius problematicus* and *Ateleaspis tessellata.*

A narrow faulted outcrop of steeply-dipping Downtonian occurs in the Stonehaven area on the north-west limb of the Mearns syncline. The strata (Campbell, 1913, for full description) rest with angular unconformity on reddened " Cambro-Ordovician " (probably Lower Ordovician) spilitic lavas, tuffs, black shales, and cherts, and pass up with no sign of unconformity into the Dunnottar Group of the Lower O.R.S. About half-way (1,400 feet) above the base of the Downtonian, in a group of greenish, brown, and grey sandstones, are some bands of sandy shale which have yielded *Hemiteleaspis heintzi* (Westoll, 1945), *Traquairaspis campbelli* (Traq.)* (Kiaer and Heintz, 1932), *Phialaspis pococki* var. *cowiensis* (White, 1946a),* with fragments of (?) *Pterolepis.* The invertebrate fauna is of Arthropoda, most of which are not diagnostic; *Dictyocaris slimoni* is common. The vertebrates have recently been shown (Westoll, 1945; White, 1946a) to indicate a truly Downtonian age; *Hemiteleaspis* suggests a low Downtonian horizon, while *Phialaspis pococki* occurs in Downtonian I. 6–7 in the Welsh Borders. A significantly earlier age than Downtonian is very highly improbable.

It has been shown (Westoll, 1945, summarizes the evidence) that the so-called " Downtonian " fish-bed (zone 9) of Lesmahagow, etc., is almost certainly earlier than the Downtonian, but probably not so old as the *Tremataspis*-beds of Oesel (K_1 zone of Baltic), which are now regarded as Lower Ludlow (Säve-Söderbergh, 1941) or even Wenlock (Lungershausen and Nikiforova, 1942). The occurrence of *Birkenia elegans* and *Thelodus scoticus* in the *Ceratiocaris* beds (zone 3) of Lesmahagow suggests that the intervening 1,700 feet of strata, with local conglomerates, do not represent a long time-interval.

Lamont (1947) has recently reviewed the invertebrate faunas of the Pentland Hills inliers, suggesting that the strata called " Ludlow " and " Wenlock " by the Geological Survey are of Gala-Tarannon age, *i.e.*, pre-Wenlock Shales. He suggests a similar age for the zones 1–3 of the Lesmahagow area, and an age " not later than Wenlock " for the so-called " Downtonian " fish-bed. The fishes of zone 3 and zone 9 are, as already noted, closely similar, and there are many difficulties in accepting a pre-Wenlock age for either. Much further work is clearly necessary (Lamont's full account is not yet published, and his preliminary comparisons seem often to be not impartial), but it is at least certain

*White and Toombs (in Watson, Westoll, White, and Toombs, 1948) now consider that *Phialaspis* is a synonym of *Traquairaspis*; the Stonehaven material is presumably referable to a single species, *T. campbelli.*

that the fish-beds of the Lesmahagow, Hagshaw Hills, and Pentlands are not of Downtonian age. A late Wenlock or early to middle Ludlow age would seem reasonable. On the other hand, the Stonehaven Downtonian is probably correctly so-called. The full stratigraphical and tectonic significance of these conclusions will be discussed elsewhere. There is now some evidence of a distinct time-break (disconformity, no Upper Ludlow, Downtonian or ?basal O.R.S.) below the Lower O.R.S. in the Lanarkshire-Ayrshire inliers, and there is a strong angular unconformity in the Pentland Hills. On the other hand, the Downtonian of Stonehaven is firmly related to the overlying Dunnottar Group by nature of sediments, presence of volcanic tuffs, and a thin lava, etc.

III. LOWER OLD RED SANDSTONE

The old controversy (esp. Murchison, 1858; Geikie, 1879; and other references in Crampton and Carruthers, 1914) on the distinctness of the fish-bearing Middle O.R.S. of the Scottish Highlands from the Lower O.R.S. of the Midland Valley is essentially settled, largely as a result of Traquair's work. But in the Highlands there is in many areas a " basement group," so far without known fossils, which in places shows evidence of contemporary volcanic activity, and is covered (often unconformably) by fish-bearing Middle O.R.S. The Rhynie outlier, with its famous fossil plants and arthropods, probably represents this basement group (Westoll, MS.), for which a Lower O.R.S. age is distinctly possible. Only in the Lorne area (Kynaston and Hill, 1908; Traquair, 1899b; Stensiö, 1932) north of the Highland Boundary Fault have Lower O.R.S. fish-remains been found.

The most important development of Lower O.R.S. is in Forfarshire (Hickling, 1908; Robson, 1948) and Kincardineshire (Campbell, 1913). The correlation may be summarized as in Table I:—

TABLE I

Kincardineshire		Forfarshire	
Strathmore Group	1,500 feet+	Edzell Shales	?1,000 feet
		Arbroath Sandstones	1,200 feet
Garvock Group (V)	c. 4,000 feet	Auchmithie Conglomerate	800 feet
		Red Head Series (V)	1,500 feet
		Cairnconnon Grits	2,000 feet
Arbuthnott Group (V)	3,000–5,000 feet	Carmyllie Series Sidlaw Series (V)	?c. 1,000 feet ?c. 1,000 feet
Crawton Group up to 1,600 feet (V)		(base not seen)	
Dunnottar Group (s.s.) (V. subordinate)	up to 6,900 feet		

V = development of volcanic tuffs and lavas.

The Dunnottar Group is almost certainly conformable on the Stonehaven beds (Downtonian). Fossils are only reasonably common in the equivalents of the Carmyllie and Cairnconnon beds. The Dunnottar group has only yielded *Parka* sp. and a poorly-preserved acanthodian spine. " *Cephalaspis lyelli* " is recorded from the Arbuthnott Group near Bervie (requires revision). In Forfarshire, the Rossie Priory, Balruddery, Tealing, Carmyllie, Farnell (very prolific!—Powrie's great collection is outstanding) and Leysmill localities (mostly quarries) are probably in the Carmyllie Group; the fauna (Hickling, 1912; Stensiö, 1932) includes cephalaspids and acanthodians like those of the overlying group. Very low in the Cairnconnon series is the locality of Reswallie, at probably much the same horizon as the Canterland Den fish-bed low in the Garvock Group. Somewhat higher is the famous Turin Hill horizon. These localities yield acanthodians (esp. Watson, 1937) such as *Mesacanthus mitchelli*, *Ischnacanthus*, *Parexus*, *Climatius*, *Euthacanthus* and *Brachyacanthus*; the problematical *Farnellia tuberculata* Tr. and *Protodus scoticus* (Newton); the remarkable cephalaspidomorph coelolepid *Cephalopterus* (" *Thelodus* ") *pagei* Pow. (Westoll, 1945); cephalaspids (Stensiö, 1932) such as *C. pagei*, *C. powriei*, *C. lyelli*, and *C. spinifer*; and *Pteraspis mitchelli* Pow. Arthropods (*Pterygotus*, " *Eurypterus*," etc., and the myriapods *Kampecaris* and *Archidesmus*) and plants (*Parka decipiens* and *Zosterophyllum myretonianum*) are characteristic. Rather higher in the Cairnconnon series are the Brechin quarries with *C. powriei* Lank., *forma typica*. There is little indication of detailed stratigraphical value in the faunas of these horizons, and many of the quarries are long abandoned. The Arbroath Sandstones and Edzell Shales and their equivalents have no known vertebrates, but *Arthrostigma gracile*, *Psilophyton princeps*, *P. goldschmidtii* and other plants have been recorded (Henderson, 1932; Lang, 1932) from high in the sequence.

South of the Firth of Tay (Wormit-Newburgh area) *Brachyacanthus scutiger*, *Ischnacanthus gracilis* and *Mesacanthus mitchelli*, with *Kampecaris*, *Pterygotus*, *Parka*, etc., have been found in the probable equivalent of the Carmyllie beds; and *Pteraspis mitchelli* from Bridge of Allan is probably from about the same horizon.

The Lorne (Argyllshire) Lower O.R.S. with *Cephalaspis lornensis* Tr., *Mesacanthus mitchelli*, *Pterygotus anglicus*, *Kampecaris forfarensis*, etc. (Kynaston and Hill, 1908), is clearly comparable with the Forfarshire main fossil-levels. King's suggestion of Downtonian age cannot be upheld.

The more westerly parts of the northern outcrop of Lower O.R.S. are so far barren. The southern outcrops are also disappointing; records of " *Cephalaspis lyelli* " from near Lesmahagow and from the Distinkhorn sandstone near Darvel (Ayrshire) need revision. The following are important points for comparison:—

(1) The Carmyllie-Cairnconnon faunas are clearly of a " Dittonian " aspect, but the species are not in general common to the Welsh Borderland succession.

(2) Downtonian genera, and also *Benneviaspis* and *Securiaspis*, are absent, suggesting perhaps a rather high Dittonian or even post-Dittonian age (?*Hemicyclaspis* sp. recorded from Leysmill needs verification and is probably incorrectly identified).

(3) The composition of the fauna (abundant acanthodians and cephalaspids, very few pteraspids, no arthrodires) is striking.

(4) Downtonian and early Dittonian equivalents are probably present in the Stonehaven, Dunnottar, Crawton, and lower Arbuthnott groups of Kincardineshire.

(5) The plants of the highest Strathmore beds are closely comparable with Dawson's Gaspé floras, which are associated with the Campbelltown fish-beds and are immediately post-Helderberg, and probably (Cooper *et al.*, 1942) Schoharie-Onondaga (*i.e.*, approximately Siegenian).

IV. MIDDLE OLD RED SANDSTONE

In several areas—*e.g.*, Pennan (Watt and Westoll, MS., reported at British Association meeting, Dundee, 1947), Gamrie (Read, 1923), Strathpeffer (Horne and Hinxman, 1914), Alness-Evanton (Peach *et al.*, 1912), Brora (Read *et al.*, 1925), and S. Caithness (Crampton and Carruthers, 1914)—an

TABLE II. MIDDLE O.R.S. AND "BASEMENT GROUP" OF HIGHLANDS

GAMRIE	INVERNESS	STRATHPEFFER	ALNESS, etc.	BRORA	S. CAITHNESS	N.E. CAITHNESS	ORKNEY	
Conglomerate Fish-bed Breccia	Hillhead Inshes Leanach Nairn & Clava fish-bed Conglomerate	—	Red and yellow sandstone, fish-beds Conglomerate	Flags, sandstone, conglomerate	Berriedale Group	John o' Groats Group Thurso Flagstone Group *Achanarras* Passage Beds Wick Flagstone Group	Eday Group Rousay Flags Upper Stromness Flags *Sandwick* Lower Stromness Flags	MIDDLE O.R.S.
Red sandstones Flags, shales, calc. nodules Red calcareous sandstones Basal conglomerate	—	Red shales, sandstones Olive shales, with calcareous nodules Sandstone and conglomerate	Red sandstones Olive and grey shales, calcareous nodules Basal breccia	Sandstones and mudstones Arkose and conglomerate	Ousdale mudstones Ousdale Arkose, etc.	Ulbster Sandstone Ulbster Mudstone Sarclet Sandstone Sarclet Conglomerate	—	"BASEMENT GROUP"

unfossiliferous " basement group " occurs, which has in places been folded and faulted and eroded before the deposition of the Middle O.R.S.

The true Middle O.R.S. (Table II) also overlaps on to the metamorphic and igneous rocks of the Highlands (*e.g.*, at Cromarty and near Nairn). On the extreme north coast, near Strathy, quite high Middle O.R.S. horizons directly overlie the crystalline rocks. The fullest sequence is known in Caithness and Orkney; in the Cromarty Firth area, and east and south of Inverness, a considerable development is also present. Generally there is only a restricted succession south of the Moray Firth. The Shetland succession (Wilson and Knox, 1936; Westoll, 1937a) is not yet described in detail.

The most important stratigraphical marker is the famous fish-band of Achanarras in Caithness, usually equated with the Sandwick fish-bed in Orkney and the " nodule bands " of Edderton, Cromarty, Nairnside, Lethen Bar, Tynet Burn, and Gamrie. This precise equation is, however, by no means certain. Thus, in the region between the Dornoch Firth and the Cromarty Firth, there are several bands of shale and mudstone with concretionary limestones in a great thickness of yellow and red sandstones; at Blackpark near Edderton one of these has yielded many members of the Achanarras-Sandwick fauna, but similar fossils have recently been found at other levels. The highly interesting possibility that the " Achanarras " fauna (for lists, see Crampton and Carruthers, 1914) may be a facies-fauna recurring through a limited thickness of strata is now receiving attention. In general, however, this fauna does seem to mark a narrow " zone."

Some interesting bio-stratigraphical points may be noted. The *Thursius macrolepidotus* fauna of the Wick Flagstone Group is not known in Orkney or elsewhere. *Coccosteus decipiens* accompanies *Thursius moy-thomasi* (Jarvik, 1948) as a common species in the Passage Beds, where *Homosteus* is unknown. In Orkney the Lower Stromness Flags include rare *Homosteus* and *C. decipiens.* The Upper Stromness Flags show no sign of the typical Thurso Group forms (*Coccosteus minor*, " *Estheria* " *membranacea*) and are 1,100 feet thick. The Rousay Flags include the Thurso Flagstone Group fauna (*C. decipiens*, *C. minor*, *Homosteus milleri*, *Dipterus* sp., *Thursius pholidotus*, etc.) and also rare *Asterolepis* (*A. orcadensis*, Watson, 1932). The Eday Flags include the John o' Groats fauna (*Microbrachius dicki*, *Pentlandia macropterus* and *Tristichopterus alatus*). The resemblances are clear, but the absence of *Thursius macrolepidotus* and *Th. moy-thomasi* (Jarvik, 1948) and of the Ackergill fauna in the Lower and Upper Stromness Flags respectively does suggest the possibility either of error in the use of the fish-band as a guide, or of considerable facies-change in a comparatively short distance in the flagstones generally.

Further south the Edderton and Cromarty nodule-beds yield the Achanarras type of fauna, but, as already indicated, further work on the " limestones " in the higher sandstones of the Tain-Edderton area is most desirable. The general sedimentary aspect characteristic of the Eday-John o' Groats beds begins significantly earlier in this area.

Near Inverness the Leanach Sandstones, overlying the Nairnside-Clava fish-bed, include typical Achanarras forms (*Pterichthyodes milleri*, *Coccosteus decipiens*, *Homosteus*, *Glyptolepis*), while the underlying fish-bed hereabouts has not so far yielded any really characteristic Achanarras forms except *Cheirolepis* sp. The Hillhead group includes *Coccosteus minor* and *Homosteus milleri*; no sign of the former species, characteristic of the Thurso and Rousay Flags, has been noted in the lower strata (cf. Orkney).

A prerequisite for further stratigraphical study is a full description of the various fossils from known horizons. A beginning has been made on the osteolepids by Jarvik (1948), but there is much material as yet undescribed.

In Shetland the Brindister Flags of the East Mainland (Wilson and Knox, 1936) include a fauna with ?*Microbrachius* sp. and ?*Tristichopterus* sp., suggesting comparison with the Eday Flags or neighbouring horizons. The Melby fish-bed of the West Mainland has an Achanarras-type fauna.

V. UPPER OLD RED SANDSTONE

Everywhere in Scotland (except perhaps in Shetland—Wilson and Knox, 1936) the Upper O.R.S.

is unconformable on earlier rocks wherever the junction is known. In the Highlands the upper limit is indefinite because of erosion; in the Midland Valley and South of Scotland it passes without apparent break into strata regarded as Lower Carboniferous.

The Elgin-Forres-Nairn region presents the most important development, though thick drift, raised beach deposits and poor natural exposures gravely hinder investigation. The Dunnet and Hoy sandstones of Caithness and Orkney are so far unfossiliferous, and may even be post-O.R.S. The more southerly outcrops, though occasionally richly fossiliferous (*e.g.*, Dura Den in Fife), are of less stratigraphical value.

The main sedimentary facies is of current-bedded sandstones, locally pebbly, and full of " clay-galls "; marly layers and cornstones are subsidiary. Vertebrate fossils are very often fragmentary. There is a strong resemblance to the Baltic and north-west Russian development, except that marine and lagoonar intercalations are lacking.

Traquair determined three successive groups of rocks in the main area:—

3. Rosebrae beds, with *Bothriolepis major*, *B. cristata*, *Phyllolepis concentrica*, *Holoptychius nobilissimus*, *Glyptopomus minor*, *Conchodus ostreiformis* and *Rhynchodipterus elginensis.*
2. Alves and Scaat Craig beds, with *Psammosteus pustulatus*, *Cosmacanthus malcolmsoni*, *Bothriolepis major*, *Holoptychius* (*nobilissimus*, *giganteus*, *decoratus*), *Polyplocodus* sp. and *Conchodus ostreiformis.*
1. Nairn Sandstones, with *Psammosteus tesselatus*, *Asterolepis maxima*, *Holoptychius decoratus*, *Polyplocodus leptognathus* and *Coccosteus magnus.*

Several important points may now be made.

(*a*) *Asterolepis* is only common in Scotland in the Nairn beds, which are definitely unconformable on Middle O.R.S., etc. But *A. thule* (Watson, 1932) is found in the Brindister Flags of Shetland (which also include *Microbrachius* and ?*Tristichopterus*), and *A. orcadensis* (ibid.) occurs in the upper Rousay Flags. Gross (1940 a, b; 1942; also Nilsson, 1941) has found *A. estonica* and *A. dellei* in the *Heterostius*-zone " D.m.3 " or " a_2 " of the Baltic.

Asterolepis also persists later than the first entry of *Bothriolepis* in Scotland (Boghole, Whitemire) and north-west Russia and the Baltic (Snetnaia and Subsnetnaia* Beds). This overlap in time may be used to mark an important zone, which in the Moray Firth is represented by the Boghole Beds (type locality, Boghole on the Muckle Burn; also at Whitemire and in the Findhorn), between the typical Nairn and (restricted) Alves beds.

Asterolepis as a " zone "-fossil must be used with caution (cf. Nilsson, 1941).

(*b*) The famous Dura Den horizon in Fife (*Holoptychius flemingi*, *Glyptopomus minor*, *Phaneropleuron andersoni*, *Phyllolepis concentrica*, *Bothriolepis hydrophila*, etc.) is clearly comparable with the Rosebrae Beds, and lies only about 150 feet (estimate) below the conventional base of the Carboniferous.

(*c*) The Farlow Sandstones fauna of Shropshire (*Bothriolepis macrocephala*, *Holoptychius giganteus*, *Sauripterus anglicus*, *Phaneropleuron*) is of Alves or Rosebrae age. Near Bristol a considerable fragmentary fauna (Wallis, 1928) indicates the possible presence of Nairn (?) or Boghole (?), and fairly certain Alves and Rosebrae, equivalents. The famous Kiltorcan assemblage of South Ireland requires urgent revision; this region should provide important evidence on O.R.S.-Carboniferous relationships.

(*d*) The faunas of the *Remigolepis*-zone (up to 800 m.), Arthrodire Sandstone and higher continental strata (up to 560+ m.) of East Greenland (Säve-Söderbergh, 1934, etc.) are nowhere represented in Britain; contemporaneous strata probably fall within the Lower Carboniferous as defined in Britain.

VI. OLD RED—DEVONIAN CORRELATION

The occasional presence of " Old Red " vertebrates in the dominantly marine Devonian of the Rhineland (Gross, 1933a, 1937), Ardennes (Leriche, 1931, etc.), Pas-de-Calais (Barrois *et al.*, 1920),

*In recent papers (Gross, 1940 a, b; 1942) these are named Snetogor and Subsnetogor (Podsnetogor).

Cornwall and Devon (Rogers, 1919, etc.), and of marine bands in the dominantly Old Red deposits of the Baltic States and north-west Russia (Gross, 1933b, 1940 a, b, 1941a, 1942; numerous references) and a few other areas (*e.g.*, Skrinkle Sandstones, South Wales) allow an outline correlation to be made. Fossil plants also afford useful evidence. (See Table III).

The Upper Oesel Group (K_1-K_4) and the Beyrichienkalk (erratic blocks in North Germany; certain Middle Devonian blocks formerly confused the situation) are here regarded as occupying the whole Ludlow (Säve-Söderbergh, 1941; Westoll, 1945; Gross, 1947).

Gedinnian strata have yielded *Pteraspis rostrata* (Ardennes, Schistes d'Oignies; Artois, Grès de Vimy) and *Pt. dewalquei* (Ardennes, Schistes de St. Hubert; Artois, Grès de Vimy) which indicate a Dittonian (of King, 1925) equivalent. In Artois (Psammites de Liévin) *Pt. gosseleti* and *Poraspis barroisi* (Leriche, 1906) probably represent a high Downtonian horizon in King's scheme. White and Toombs (in Watson *et al.*, 1948) have redefined the Downtonian-Dittonian boundary at a somewhat lower level; the Psammites de Liévin would be early Dittonian in their usage.* The still lower strata at Liévin (Shirley, 1938), including the Calcaire de Liévin, may all be post-Ludlow. The Gedinnian of the type-area is transgressive. It seems reasonable to extend this division of the Devonian down to the top of the uppermost Ludlow. In this case the Downtonian and at least most of the Dittonian are of (extended) Gedinnian age.

The lower (Fraenkelryggen) division of the Red Bay series of Spitsbergen (Føyn and Heintz, 1943) includes *Corvaspis* and " *Phialaspis* " (= *Traquairaspis*) in its basal layers, which suggests about a Downtonian I 7–8 (King) or uppermost Downtonian (White and Toombs) horizon. The remainder of the Red Bay series is probably of Dittonian age (of White and Toombs). In Podolia (Kosłowski; Zych; Brotzen; Stensiö, 1944, for references) the " Old Red " includes faunas (Ét. I, II) of Dittonian type, and the uppermost Czortkow (Übergangsschichten) also has a fauna of decidedly Dittonian aspect, resembling that of the upper (Ben Nevis) division of the Red Bay series. The main Czortkow vertebrate-fauna cannot be earlier than late Downtonian (King) and may well be early Dittonian, even in King's sense. The upper part of the Podolian " Old Red " (Ét. III) includes *Rhinopteraspis* spp. indicating a probable Siegenian age. The Rhineland Siegenian yields *Rh. dunensis*, found also in the Breconian of Britain (Senni Beds in South Wales—White, 1938). A varietal form occurs in possible Dittonian strata in Pembrokeshire (White, 1938).

The Wood Bay Series of Spitsbergen has a curiously mixed fauna, briefly reviewed by Føyn and Heintz (1943). The Coblenzian vertebrates of the Rhineland (Gross, 1933a, 1937) represent a very fragmentary sample of rather similar faunas. The problems of the Wood Bay fossils (presence of such " Middle O.R.S." forms as *Homosteus*, *Heterostius* and *Actinolepis* in the upper part of the middle (Lykta) and the upper (Stjørdalen) divisions, with persistent Arctolepida (" phlyctaenaspids "), cephalaspids and pteraspidomorphs) reflect the lack of comparable faunas elsewhere. *Gigantaspis*, regarded as related to *Rhinopteraspis*, and a species of the genus *Benneviaspis* (otherwise known in the middle Red Bay and the Lower Dittonian of King) are found in the lowest (Kapp Kjeldsen) division, which may be provisionally equated with the Siegenian.

The Eifelian of the " marine " areas has yielded little of value. The Givetian *Stringocephalus*-beds of the Rhineland yield *Gerdalepis rhenana* (Gross, 1941b; probably a relative of *Pterichthyodes*), *Coccosteus*, *Heterostius* and *Dipterus*, which have a " Middle O.R.S." aspect. The flora of the Honselerschichten (lower Givetian) very closely resembles that of the Moray and Cromarty fish-beds and the Stromness and Thurso Flagstone groups, and similar floras (Thomson, 1940) occur in the Pernau sandstones of the Baltic. In the Baltic (Gross, 1933b, 1940a, b., 1941a, 1942) the lower " Mittleres Old-Red " (D.m.1–2, a_1) includes a rich vertebrate fauna with resemblances to that of the Thurso, Stromness, and Rousay beds, while D.m.4–5 (a_3–a_4) have a Nairn-type fauna. The overlying " Marin-lagunäre " beds include a lower division (D.o.1 = b_1, the Snetogor or Snetnaia beds with the *cellulosa*-marl at the base) with a Boghole-type fauna; *Bothriolepis* even appears in the upper part

*White (*Bull. Brit. Mus. Nat. Hist.*, Geology I, No. 3; 1950) has, since this paper was written, published a more extended version which fortifies the above conclusions.

TABLE III. DEVONIAN–OLD RED SANDSTONE CORRELATION

	DEVON	WELSH BORDERS	CENTRAL AND SOUTH SCOTLAND	SPITSBERGEN	MORAY FIRTH	CAITHNESS	ORKNEY	SHETLAND	EAST GREENLAND	BALTIC STATES	NORTH WEST RUSSIA	WEST RUSSIA
LOWER TOURNAISIAN		Carboniferous Limestone Z_1	Calciferous Sandstone			↑? ↑	↑? ↑		? Arthrodire Sandstones		Coal-measures	Coal-measures C_1^h Tschernyschino
STRUNIAN	Pilton Beds	Limestone Shales K	Series ↓?			↑?	↑?		? Remigolepis-Series	Marine strata (Lithuania)		Upa Malewko-Muraevna
FAMENNIAN	Baggy & Marwood Pickwell Down Sandstone Morte Slates	Upper O R S	Upper O R S		Rosebrae	Dunnet Sandstone	Hoy Sandstone		Phyllolepis-Series Strata without Phyllolepis	h, g, e/f — D o 4	"Old Red" facies with marine bands	Dankow-Lebedjan Jeletz Jewlanowo
FRASNIAN	Ilfracombe Beds				Alves-Scaat Craig Boghole	↓?	↓?			d D o 3 c D o.2 b D o I	Buregi | | Pskow Snetogor	Woronesch Semiluki Schtschigri
GIVETIAN	↑?			Fish-cleft Wijde Bay	Nairn Sandstones, etc.	John-o'-Groats Thurso Group	Eday Group Rousay Group Stromness Flags	Bressay Flags Brindister Flags (Melby fish-bed)	Middle O.R.S. (Canning Is. etc)	a_4 D.m 5 a_3 D m 4 a_2 D.m.3 a_1 D.m.2, D.m.1	Subsnetogor Oredesch Luga Narowa Pernau	Stary-Oskol
EIFELIAN	Hangman Grits S. DEVON			Grey Hoek	Fish-bed Conglomerate	Passage-Beds Wick Group						
EMSIAN	↓ S. Devon: Staddon Grits			Wood Bay C, B	↑? Basement Group	↑? Basement Group						PODOLIA
SIEGENIAN	Lynton Beds S. Devon: Mead-foot Beds	↑? Breconian	Strathmore group	Wood Bay A	↓?	↓?						"Old Red" III, II, I
GEDINNIAN	Foreland Grits S. Devon: Dart-mouth Slates	Dittonian Downtonian	Garvock Arbuthnott Crawton Dunnottar Stonehaven	Red Bay B, A						? Beyrichien-kalk		Czortkow Borszczow
LUDLOVIAN		Whitcliffe Flags Mocktree Shales Aymestry Lstn Lower Ludlow Shls	Lesmahagow Fish-bed							K_4 K_3 K_2 K_1		Skała

ARDENNES	ARTOIS
Sch. de St. Hubert Sch. d' Oignies Sch. de Mondrepuits Conglomerate	Grès de Vimy Grès de Pernes Psammites de Liévin Sch. de Mericourt | | Calc. de Liévin

Eroded surface

Unconformable junction

Buregi | | Pskow — Formations from, e.g., Pskow to Buregi inclusive

Wood Bay: C — Stjørdalen division; B — Lykta division; A — Kapp Kjeldsen division

Red Bay: B — Ben Nevis division; A — Fraenkelryggen division

of the underlying Subsnetogor (D.m.5 = a_4). The upper part (D.o.1–3, b–d) of these strata include faunas of Alves-Scaat Craig aspect, with also *Rhynchodus* and *Ptyctodus*; marine fossils (*Spirifer fimbriatus*, *Sp. muralis*, " *Rhynchonella* " *meyendorfi* and " *Rh.*" *livonica*) indicate the horizon of the *cuboides*-limestone of Timan and the Schtschigri beds of the Orel-Woronesch Devonian.* The Schtschigri beds directly overlie the Stary-Oskol beds with *Stringocephalus burtini* (Givetian), and presumably represent the lowest Frasnian. *Manticoceras intumescens* is recorded from the Jewlanowo beds and, though needing revision, suggests that part of these beds is also Frasnian. The Jeletz and Dankow-Lebedjan beds may be regarded as Famennian, the Malewko-Muraewna and Upa as Strunian (Zalessky, 1949).

The " Oberes Old-Red " of the Baltic and north-west Russia (D.o.4, e–h) include fish-faunas of Alves-Scaat Craig and Rosebrae types, including *Phyllolepis* in the upper part in Russia. Three marine-bands allow reasonable correlation with the Jewlanowo (?Woronesch), Jeletz, and Dankow-Lebedjan. Still higher strata in Lithuania have yielded a marine fauna of " Carboniferous " (?Strunian) aspect; Gross (1940b) has found *Holoptychius* and *Bothriolepis* in corresponding strata.

The Famennian in several areas (North Devon, Belgium, Northern France) has yielded *Bothriolepis*, *Holoptychius* and, in the higher parts, *Phyllolepis*. It seems probable that an " Old Red " facies with similar fossils (also *Remigolepis*, etc.) persisted into Strunian and even into Tournaisian times in some regions, such as East Greenland (Westoll, 1940; but cf. also Jarvik, 1948, for an opposition view).

VII. LOWER CARBONIFEROUS

The greatest development is in the Midland Valley; there is practically none in the Highland sector, but an interesting sequence is found in the Border country (especially Eskdale and Berwickshire). An excellent account of the Scottish Carboniferous is given by Macgregor (1930) and summarized in Macgregor and MacGregor (1948). There is a striking faunal and floral break in the " Millstone Grit," so that a division into Lower and Upper Carboniferous is natural and useful.

In the Midland Valley the stratigraphical succession is as follows† (omitting the important volcanics):—

" *Millstone Grit*." Possibly includes a crypto-unconformity. Lower third in (goniatite) zone E_2 or H_1(?), and floral-zone A; upper part possibly in goniatite-zone G, floral-zone C, (mussel) *lenisulcata* zone. Up to 1,100 feet.

Carboniferous Limestone Series.

3. *Upper Limestone Group.* Includes " D_3 " type of coral-brachiopod fauna; lies in coral-zone 4, goniatite-zone E_2(?); *i.e.*, is " Namurian " in age. Up to c. 1,650 feet.
2. *Limestone* (*Edge*) *Coal Group.* Corresponding strata in North England include " D_3 " fossils; in coral-zone 4, goniatite-zone ?E_1 or ?E_2 (? early " Namurian "). Up to c. 1,300 feet.
1. *Lower Limestone Group.* Fauna of D_2 type; coral-zone 3, possibly goniatite-zone P_2 (?and E_1). Upper Viséan, possibly also earliest " Namurian." Up to c. 700 feet.

Calciferous Sandstone Series.

2. *Oil Shale Group.* Faunas indicate correlation with $C_2 - D_1$ (? even basal D_2, Hill 1938-41, p. 30); coral-zone 1–2. Lower and Middle Viséan. Up to c. 3,800 feet.
1. *Cementstone Group.* Downward passage into Upper O.R.S. in many places. A different facies in Fife; the Randerstone beds, probably representing Upper Cementstone Group of Lothians, are probably of C_1 age. Up to c. 700 feet.

In the Border country, the base of the Carboniferous is taken arbitrarily at the Birrenswark lavas (Eskdale-Liddesdale and Solway) and Kelso " traps "; but lavas have been proved by borings near Kelso in the Cornstone group of the Upper O.R.S.

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*The German transliterations are used here; cf. Gross, 1940b; Zalessky, 1949.

†Floral zones from Dix (1934); goniatite-zones after Bisat (1924); mussel-zones from Weir and Leitch (1936); coral-zones from Hill (1938-41).

TABLE IV

ESKDALE-LIDDESDALE		*BERWICKSHIRE*	
Carb. Limest. Series	c. 1,150–1,450 feet		
Calcif. Sstn. Series.			
6. Lawston Linn and Lewis Burn Coal-group (S_1–S_2)	400–500 feet		
5. Glencartholm Volcanic Group (C_2)	300 feet		
4. Fell Sandstone Group (C_2)	400–600 feet		
3. Cementstones Group (up to C_1–C_2)	1,200–1,500 feet	3. Cementstones	2,500–3,000 feet
2. Whita Sandstones	700 feet	2. (Freestones in Northumberland)	
1. Birrenswark Lavas.		1. Kelso traps.	
Upper O.R.S.		*Upper O.R.S.*	

Faunas of K-Z age have never been proved in Scotland; in Northumberland beds low in the Cementstones have yielded *Pustula interrupta*, suggesting a Z_2 age.

The Cementstones have provided important fish-faunas at Foulden in Berwickshire (White, 1927), from near the base of the sequence (?Tournaisian), and at Tarras Waterfoot in Eskdale (Traquair, 1881, 1890b; Moy-Thomas, 1937), from c. 500 feet above the Whita Sandstone. *Styracopterus* may be a good guide-fossil; the palaeoniscids are not known from higher strata (see Moy-Thomas, 1938).

The Glencartholm Volcanic Group (probably C_2, lowest Viséan) includes a remarkable fauna of some 20 genera of fishes, many invertebrates, and plants. (Traquair, 1881, 1890b; Moy-Thomas, 1936; Moy-Thomas and Dyne, 1938 and refs.)

In the Midland Valley, Traquair (1890a, 1901, 1903) has noted the distribution of the fishes. The most important horizons may be listed in stratigraphical order:—

Upper Limestone Group.		Roof-shale of South Parrot Coal, Niddrie.
Limestone Coal Group.		Loanhead No. 2 or Borough Lee Ironstone—very prolific.
		Loanhead No. 1 Ironstone.
	A.	Blackband Ironstone of Niddrie.
Lower Limestone Group.	M.	Hosie Limestones—marine elasmobranchs.
		Gilmerton Ironstone—prolific.
	M.	Hurlet Limestone—marine elasmobranchs.
Oil Shale Group.	A.	Kinghorn-Abden bone-bed; *Crangopsis*-bed of Ardross (White, 1937).
		Dunnet Shales—prolific.
		Burdiehouse Limestone—prolific.
		Pumpherston Shales (No. 3, " curly " 8)—prolific.
		Wardie Shales—very prolific.

These are mainly in the Lothians. The most prolific locality in Fife is Pitcorthie, in the Oil Shale Group (Traquair, 1901, lists the Fifeshire localities). One important horizon—the Gullane Fish-bed (Traquair, 1907)—is not indicated above. According to the Geological Survey it is near the very top of the Oil Shale Group, but Traquair notes that the fishes show most agreement with those of the Wardie Shales, near the base of that group. But one of the most remarkable features of Traquair's results is the sameness of the aspect of the fishes from the Wardie Shales right up into the Carboniferous Limestone Series, with significant numbers of new forms appearing at and above the Borough Lee horizon.

Traquair has also noted that a well-marked " estuarine " (perhaps rather " deltaic ") fauna marks the Oil Shale Group and Carboniferous Limestone Series, with two other facies recurring at intervals—

a " marine " assemblage marked " **M** " in the list above (especially in the Lower Limestone Group), known also from the marine limestones of England and Ireland; and the curious " Abden fauna," marked " **A** " in the list above, which seems also to represent more marine conditions.

The fossil tetrapods of the Lower Carboniferous (Watson, 1926) are much later in age than was once thought. The earliest known is an unnamed lepospondyl (Romer, 1947, p. 320) from the Wardie Shales; another is from the Pumpherston No. 3 " Curly " shale. *Dolichopareias disjectus* Wats. and *Otocratia modesta* Wats. (cf. Westoll, 1942) are from the Burdiehouse Limestone, and *Adelogyrinus simorhynchus* Wats. from the Dunnet Shale. These are all probably referable to the (C_2-S_2 or D_1) section of the Viséan; Watson regarded them as Tournaisian. The Gilmerton Ironstone (late Viséan probably) has the earliest Loxommoid (*Loxomma allmanni* Hux.), *Pholidogaster pisciformis* H., and possibly *Crassigyrinus scoticus* Wats. The Borough Lee (Loanhead No. 2) Ironstone (Namurian) yielded *Spathicephalus mirus* Wats. and probably also the femur called *Propappus traquairi* Watson (1914).

The " break " in the fish-faunas at the " Millstone Grit " is very striking.

VIII. UPPER CARBONIFEROUS

The Scottish " Millstone Grit " has not yet provided any vertebrates.

The Coal Measures have provided important vertebrates only in the Midland Valley, where the entire development is comparatively thin (Macgregor, 1930):—

	Central Coalfield (west)	Midlothian	East Fife
Barren Red Measures ...	960 feet+ ...	550 feet+ ...	1,000 feet+
Productive Measures	1,220 feet ...	1,600 feet ...	1,770 feet

All the known vertebrates are from the Productive Measures. Recent work involving the use of marine bands, non-marine lamellibranchs (" mussels "—Weir and Leitch, 1936; Trueman, 1941, 1947) and plants (Walton, Weir, and Leitch, 1938) shows that these measures are almost exactly equivalent to the *Middle* Coal-Measures of Yorkshire, *not* to Lower Coal Measures (though the very top of the Lower Coal Measures may be represented). Trueman uses the terms Ammanian (*lenisulcata*-zone to top of *similis-pulchra* zone, Westphalian A+B+part of C) and Morganian (*phillipsi*- and *tenuis*- zones, Westphalian upper C+D); the Scottish vertebrate-faunas are Ammanian.

Traquair (1903, etc.) records 41 species from the west of Scotland, of which 18 occur at Niddrie in the Lothians (Four Foot Coal; probably *ovalis*-zone) and seven at Smeaton (Jewell? roof-shale: higher in the *ovalis*-zone; Hugh Miller reports having seen " reptilian footprints " in the roof of one of the seams at Smeaton). The fish fauna is extremely closely comparable with that of the Lower and Middle Coal Measures of Staffordshire and Yorkshire, but has almost nothing in common with the Lower Carboniferous fauna.

Tetrapod remains are discussed by Watson (1926). Only three important localities are known:—

Airdrie Blackband Ironstone near Airdrie: upper *modiolaris*-zone, *i.e.*, probably low in Westphalian B. *Anthracosaurus russelli* Hux., *Loxomma acutirostris* Wats., *Baphetes latirostris* Wats.

Parrot Coal, Pirnie, Fife: probably in or near *modiolaris*-zone, near Westphalian A-B boundary. *Megalocephalus* (*Orthosauriscus*) *platycephalus* (Bark.), *Baphetes kirkbyi* Wats., *Palaeogyrinus decorus* Wats.

Palacecraig Blackband Ironstone, Airdrie: about middle of Lower *similis-pulchra* zone, *i.e.*, near top of Westphalian B. *Megalocephalus* (*Orthosauriscus*) *platycephalus* (Bark.).

Vertebrates have not yet been found in the Barren Red Measures.

IX. PERMO-TRIASSIC

All the Permo-Triassic rocks of Scotland are dominantly arenaceous, and of continental red-beds

or of aeolian-bedded type. Fossils, almost exclusively vertebrates, are very rare. There are two main regions of interest—the Solway and the Elgin-Lossiemouth areas.

In the Solway region the Dumfries Sandstones are referred to the Permian, and are probably the lateral equivalents of the Penrith Sandstones (Upper Permian) of Cumberland. Tracks and footprints (Hickling, 1909) were obtained from several quarries (*e.g.*, Corncockle Muir), and Hickling shows that there is a close comparison between them and tracks from undoubted Upper Permian (*pace* Sherlock) at Mansfield, and a general resemblance to the Penrith tracks. The overlying Annan Sandstones represent the St. Bees Sandstone of Cumberland (Barrett, 1942; references). Footprints of "*Labyrinthodon*" are reported from near Annan.

The Moray Firth development (Watson and Hickling, 1914, etc.) is now being revised by the writer. A provisional stratigraphical summary follows. (References in Read and MacGregor, 1948; Watson, 1942; and von Huene, 1925.)

3. Sandstones of Lossiemouth, Spynie, and Findrassie..c. 200 feet. Fauna includes *Telerpeton*, *Brachyrhynodon*, *Hyperodapedon*, *Stenometopon*, *Scleromochlus*, *Stagonolepis*, and *Saltopus*. A Middle or lower Upper Triassic age (Lettenkohle) is indicated. The sandstones are dominantly aeolian and dune-bedded, the fossils occur mostly near the base.
2. Burghead Sandstones, water-laid, pebbly (new name)...c. 250 feet.
1. Sandstones of Cutties Hillock and Hopeman-Cummingstown..................................c. 200 feet. Aeolian sandstones, dune-bedded. At Cutties Hillock yielded the anomodonts *Gordonia* and *Geikia*, with the pareiasaur *Elginia*. Footprints, especially at Cummingstown, are closely comparable (Hickling, 1909) with those of Mansfield and Penrith. An uppermost Permian horizon is probable.

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THE VERTEBRATE FAUNAS OF THE OLD RED SANDSTONE OF THE WELSH BORDERS*

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ABSTRACT

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Recent investigations of the vertebrate faunas of the Downtonian and Dittonian strata of the Anglo-Welsh region have shown that these rocks may be divided into well-marked palaeontological zones. The division between the Dittonian and Downtonian Series is placed approximately at the level of the so-called " *Psammosteus* Limestones " (which are themselves slightly diachronic), the Dittonian being characterized by *Pteraspis*, the Downtonian by species of *Traquairaspis* (=*Phialaspis*) in the upper part, and by *Cyathaspis* and *Hemicyclaspis* in the lower. It is argued that as far as this, the type-area, is concerned, the natural palaeontological break between the Silurian and the Old Red Sandstone is at the base of the Ludlow Bone-bed, and the Downtonian strata are therefore included in the Devonian System as part of the Lower Old Red Sandstone. That the cause of the break is, in this case, undoubtedly due to the change from marine to more continental conditions in no wise invalidates the argument, as some authors contend: indeed, organic evolution is in itself obviously too gradual to allow the use of fossils as a means of stratal division without the discontinuity due to a change in conditions (and therefore of the type of fauna) or to a marked non-sequence.

It is considered that the vertebrate faunas of the Lower Old Red Sandstone are mostly of the nature of isolated irruptions into the main area and correlation thereby outside the area must not be over-emphasized.

At the upper end of the formation the discovery by W. N. Croft of *Coccosteus* cf. *cuspidatus* (= *C. decipiens*) in apparent association with *Bothriolepis* and *Holoptychius* in the upper Plateau Beds, suggests that we may possibly be dealing with a condensed representative of part, at any rate, of both the Middle and Upper O.R.S. of Scotland.

*For discussion following the presentation of this and other papers, see p. 26.

LE PERMO-CARBONIFÈRE CONTINENTAL PORTUGAIS*

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RÉSUMÉ

Le Permo-Carbonifère continental portugais est aujourd'hui assez bien connu.
Un résumé de la paléontologie et de la stratigraphie sera donné dans cette communication.

Le Permo-Carbonifère de faciès limnique est représenté au Portugal par plusieurs affleurements. Bien que de dimensions assez reduits, ils ont une certaine importance industrielle et leur connaissance a beaucoup d'intérêt du point de vue géologique.

Au Sud du Tage se trouve le bassin houiller de Santa Suzana, appartenant au Westphalien D.

Aux environs de Coimbra, à Buçaco, affleure l'Antunien inférieur.

À l'Est de Porto se trouve une bande étroite de Carbonifère continental, appartenant au Stéphanien moyen, qui se prolonge dans la province de Beira.

Le Westphalien D est représenté au Nord du Douro par deux petits affleurements, l'un près de Porto (Ervedosa), l'autre plus au Nord, aux environs de Povoa de Varzim (São Felix de Laundos).

Au point de vue industriel c'est l'affleurement du Stéphanien moyen qui possède une importance économique. Il fournit un charbon anthraciteux, exploité dans deux mines principales (São Pedro da Cova et Pejão).

À Santa Suzana on a exploité de la houille, mais le bassin est considéré aujourd'hui comme épuisé.

Les formations autuniennes de Buçaco ne montrent que quelques minces filets de houille.

Dans ce qui concerne la géologie ces affleurements présentent un intérêt spécial, car ils sont en rapport étroit avec la tectonique du pays.

I. WESTPHALIEN

(*a*) *Bassin houiller de Santa Suzana.*—Les dépôts carbonifères de Santa Suzana sont formés par des schistes argilleux, des grès, des conglomérats et des brèches à gros éléments. Ils contactent d'un côté avec les schistes dévoniens ou archéens, tandis que de l'autre ils sont en rapport avec des porphyrites, dont il y a abondance de fragments dans les éléments des conglomérats et brèches.

Les couches ont été plissées et disloquées; elles sont souvent coupées par des failles.

Les schistes sont très fossilifères; en plus des fossiles végétaux, on connait des empreintes d'arthropodes.

La flore comprend:—

Pecopteris dentata Brongn., *Pecopteris cyathea* Schloth., *Pecopteris unita* Brongn., *Pecopteris Pluckeneti* Schloth., *Pecopteris crenulata* Brongn., *Pecopteridium Jongmansi* P.B., *Alethopteris Davreuxi* Brongn., *Linopteris obliqua* Bunb., *Neuropteris Machadicostai* Teix., *Sphenopteris obtusiloba* Brongn., *Mariopteris* cf. *nervosa* Brongn., *Sphenophyllum emarginatum* Brongn., *Annularia sphenophylloides* Zenker, *Annularia stellata* Schloth., *Calamites Suckowi* Brongn., *Calamites Cisti* Brongn., *Calamites undulatus* Sternb., *Lepidodendron dichotomum* Sternb., *Stigmaria ficoides* Sternb., *Lepidophyllum majus* Brongn., *Sigillaria* (nombreuses espèces de type cannelé), etc.

La faune comprend différents insectes, parmi lesquels *Phyloblatta cardosiana* Teix., des restes d'*Arthropleura* et d'*Eurypterus*.

Il s'agit d'un bassin autoctone.

*For discussion following the presentation of this and other papers, see p. 26.

Au point de vue de l'âge, la flore conduit à paralléliser la formation de Santa Suzana avec le Westphalien D.

(*b*) *Affleurements de Ervedosa et de São Felix de Laundos.*—Ce sont deux petits lambeaux, en forme de bande étroite, en contact avec des schistes siluriens. Le premier est formé par des schistes bruns ou jaunes, très fossilifères; le lambeau de São Felix semble être la continuation du précédent vers le Nord-Ouest. En plus des schistes bruns et jaunes ce dernier contient aussi des conglomérats à gros éléments; les fossiles sont rares.

La flore recueillie dans les deux gisements comprend:—

Pecopteris dentata Brongn., *Pecopteris unita* Brongn., *Pecopteris Pluckeneti* Schloth., *Pecopteris crenulata* Brongn., *Pecopteridium Armasi* Zeiller, *Pecopteridium Cuvelettei* P.B., *Alethopteris lonchitifolia* P.B., *Linopteris obliqua* Bunb., *Linopteris Florini* Teix., *Neuropteris ovata* Hoff., *Annularia stellata* Schloth., *Calamites gigas* Brongn., *Lepidodendron aculeatum* Sternb., *Lepidophyllum majus* Brongn., etc.

L'ensemble de cette flore nous amène à placer les formations qui la contiennent dans le Westphalien D; elles sont synchroniques avec celles du Sud du Tage.

II. STÉPHANIEN

Le Stéphanien est représenté par un affleurement très allongé, comprimé entre des schistes siluro-dévoniens et anté-siluriens. Il s'etend depuis les environs de Porto jusqu'à la région de Vizeu; son orientation est Nord-Ouest—Sud-Est.

L'affleurement a été coupé et métamorphisé par une intrusion granitique, dont on parlera plus loin.

On observe, interstratifiées dans la formation, des roches éruptives du type porphyre granitique. Celles-ci sont postérieures au couches inférieures de la série mais antérieures aux couches supérieures, dans lesquelles il y a des gros galets de cette roche.

Les roches les plus communes dans cette formation sont les schistes, les grès, les arkoses et les conglomérats. Les fossiles y sont très abondants, en particulier les végétaux. Les animaux sont représentés par des empreintes d'insectes, philopodes et mollusques.

La flore comprend un grand nombre d'espèces:—

Lebachia parvifolia Florin, *Ernestiodendron filiciforme* Florin, *Pecopteris feminaeformis* Schloth., *Pecopteris unita* Brongn., *Pecopteris hemitelioides* Brongn., *Pecopteris polymorpha* Brongn., *Pecopteris lepidorachis* Brongn., *Pecopteris arborescens* Schloth., *Pecopteris cyathea* Schloth., *Pecopteris Sterzeli* Zeiller, *Pecopteris Viannae* Teix., *Pecopteris Bioti* Brongn., *Callipteridium gigas* Gutbier, *Callipteridium pteridium* Schloth., *Alethopteris Grandini* Brongn., *Linopteris Germari* Giebel, *Odontopteris genuina* Grand'Eury, *Odontopteris Brardi* Brongn., *Sphenopteris pecopteroides* Landsk., *Sphenopteris Matheti* Zeiller, *Neuropteris cordata* Brongn., *Neuropteris Zeilleri* Lima, *Neuropteris Planchardi* Zeiller, *Neuropteris auriculata* Brongn., *Mixoneura neuropteroides* Goeppert, *Diplothmema Ribeyroni* Zeiller, *Taeniopteris jejunata* Grand'Eury, *Taeniopteris Bertrandiana* Teix., *Sphenophyllum oblongifolium* Germar, *Sphenophyllum longifolium* Germar, *Sphenophyllum Costae* Sterzel, *Sphenophyllum verticillatum* Schloth., *Dicranophyllum lusitanicum* (Heer) Lima, *Dicranophyllum gallicum* Grand'Eury, *Plagiozamites Planchardi* Renault, *Rhacopteris Gomesiana* (Heer) Teix., *Sigillaria Brardi* Brongn., *Annularia stellata* Schloth., *Annularia sphenophylloides* Zenker, *Calamites Suckowi* Brongn., *Calamites Cisti* Brongn., *Calamites Waldenburgensis* Kidston, *Asterophyllites equisetiformis* Schloth., *Asterophyllites longifolius* Sternb., *Cordaites* sp., etc.

La série d'insectes recueillis jusqu'à présent est très remarquable. Elle comprend beaucoup de formes des Archimylacridae (*Phyloblatta*, *Eneriblatta*), des Hemimylacridae (*Lusitanomylacris*, *Stephanomylacris*), des Dictyoneuridae (*Valdeania*, etc.), etc.

À côté des insectes il y a des *Estheria*, dont une forme se rapproche de l'*E. cebennensis*.

Les mollusques sont représentés par des *Anthracomya.* L'un de ces mollusques est très voisin de *A. prolifera*; mais il y a une autre espèce que j'ai décrit sous le nom de *A. lusitanica.*

L'ensemble de la flore et de la faune marque nettement la position des formations correspondantes dans la partie supérieure du Stéphanien moyen.

III. AUTUNIEN

Les dépôts de l'Autunien forment une grande partie de la montagne de Buçaco. Les couches sont orientées dans la direction Nord-Sud et se trouvent en contact avec des schistes siluriens et anté-siluriens. Parfois, elles sont recouvertes, en discordance, par des formations rouges du Rhétien.

Les conglomérats sont les roches prédominantes. Il y a aussi des schistes argileux et des grès arkosiques.

Quelques unes de ces couches argileuses sont très fossilifères, surtout en empreintes de végétaux. La faune ne comprend qu'un exemplaire de *Eurypterus* et une aile d'insecte paléodictioptère.

Parmi les espèces végétales on signale:—

Lebachia parvifolia Florin, *Lebachia Goeppertiana* Florin, *Lebachia laxifolia* Florin, *Callipteris conferta* Sternb., *Sphenopteris pecopteroides* Landsk., *Pecopteris hemitelioides* Brongn., *Pecopteris cyatea* Brongn., *Pecopteris unita* Brongn., *Pecopteris pòlymorpha* Brongn., *Pecopteris lepidorachis* Brongn., *Pecopteris Bioti* Brongn., *Pecopteris leptophylla* Bunb., *Pecopteris Sterzeli* Zeiller, *Pecopteris Viannae* Teix., *Callipteridium gigas* Gutbier, *Callipteridium regina* Roemer, *Diplothmema Ribeyroni* Zeiller, *Odontopteris Brardi* Brongn., *Odontopteris Osmundaeformis* Schloth., *Neuropteris Zeilleri* Lima, *Neuropteris Planchardi* Zeiller, *Neuropteris crenulata* Brongn., *Mixoneura neuropteroides* Goeppert, *Linopteris latenervosa* Teix., *Taeniopteris jejunata* Grand'Eury, *Taeniopteris multinervis* Weiss, *Sphenophyllum oblongifolium* G. e K., *Sphenophyllum Thoni* Mahr., *Sphenophyllum augustifolium* Germar, *Asterophyllites equisetiformis* Schloth., *Annularia sphenophylloides* Zenker, *Annularia stellata* Schloth., *Calamites Suckowi* Brongn., *Cordaites Renaulti* Lima, *Cordaites* sp., etc.

L'ensemble caractérise nettement l'Autunien inférieur.

* * * * *

C'est donc à la fin du Westphalien, quand la mer moscovienne occupait encore une grande partie de ce qu' est aujourd'hui le Sud du pays, que se sont formé les premiers dépôts continentaux du Portugal, accumulés dans les bassins limniques de Santa Suzana et de Ervedosa-São Felix.

Toutefois l'existence de terres émergées depuis le Carbonifère inférieur est démontrée par les végétaux flottés trouvés abondamment dans toute la série marine dinantienne-moscovienne de l'Alentejo et d'Algarve. Ces végétaux comprennent surtout *Asterocalamites scrobiculatus*, *Mesocalamites Haueri*, *M. cistiformis*, et encore restes d'*Annularia* et *Sphenopteris.*

À la fin du Westphalien les mouvements asturiens ont affecté fortement le Portugal; les sédiments des bassins limniques, comme ceux du Carbonifère marin, ont été comprimés et plissés. La mer, par un mouvement rapide de régression, s'est retirée des territoires de l'Alentejo et de l'Algarve.

Il y a un grand intervale en rapport avec lequel on ne connait pas de dépôts dans le territoire portugais.

Beaucoup plus tard s'est établi le bassin limnique de Douro-Beira, où se sont déposées les formations du Stephanien moyen. Ce bassin était assez étendu.

La sédimentation a été interrompue par un mouvement orogénique, cause du plissement des couches. Une intrusion granitique, certainement en rapport avec ce mouvement, a métamorphisé et coupé les formations en plusieurs endroits.

Au début du Permien se forme le bassin de Buçaco, où s'est déposé une grande épaisseur de sédiments.

Après la formation de ces dépôts un nouveau mouvement orogénique a affecté le territoire. Les couches de l'Autunien ont été comprimées et plissées. Sur ces couches redressées à la verticale on voit reposer en quelques endroits des formations du sommet du Trias ou du Rhétien, très peu inclinées. On a attribué le plissement aux mouvements saaliens.

À ce moment les granites du massif ancien du Portugal étaient formés. Dans les conglomérats de l'Autunien il y a des cailloux de granite et de pegmatite. Le premier est un granite à grain fin, à deux micas et tourmaline, avec microcline et un feldspath kaolinisé. Le second est une pegmatite graphique, composée de quartz, de microcline, de muscovite et d'un feldspath kaolinisé. On signale aussi des cailloux de quartz et tourmaline.

Comme il y a un granite qui métamorphise et coupe le Stéphanien moyen, il faut conclure à l'éxistence d'une intrusion granitique postérieure à cet étage.

La trouvaille de cailloux de granite et de pegmatite dans l'Autunien de Buçaco démontre, d'autre part, que le granite de Beiras affleurait déjà au moment de la formation du dépôt.

La même roche a fournit une très grand partie du matériel des dépôts du Rhétien.

À mon avis cette intrusion se place entre le Stéphanien moyen et l'Autunien inférieur.

L'occurrence de galets de granite dans le conglomérat de la base du Stéphanien moyen et l'abondance de formations arkosiques dans celui-ci démontre qu'il y avait déjà à ce moment des affleurements granitiques aux environs. Le granite des galets est une variété à muscovite et orthose, avec apatite.

Peut-être il y a eu une intrusion granitique au Portugal en rapport avec des mouvements asturiens.

Il faut signaler, encore, l'existence de granites plus anciens, anté-stéphaniens et même anté-siluriens.

En effet, le conglomérat du Westphalien D de Santa Suzana contient des galets d'un granite à orthose et albite et à biotite, muscovite et apatite, provenant certainement d'un affleurement du voisinage.

Mais les galets les plus communs dans les conglomérats du Westphalien D de Santa Suzana sont ceux de porphyrite. Ces roches forment de grandes étendues aux environs. Il est évident que leur mise en place est antérieure au Westphalien D. Elles sont, d'autre part, post-siluriennes, du fait qu'elles recoupent le Silurien supérieur.

Les dépôts du Permo-Carbonifère portugais ont été atteints, comme je l'ai exposé, par des mouvements différents. Cela explique donc la différente orientation des plis. Tandis que les plissements de l'Autunien sont orientés dans la direction Nord-Sud, ceux du Stéphanien, du Westphalien et du Carbonifère marin suivent la direction Nord-Ouest—Sud-Est.

Ces conclusions tectoniques déduites de l'étude du Permo-Carbonifère sont très importantes, surtout pour l'interprétation de la génèse de beaucoup de gisements minéraux du Portugal, car ces gisements sont en rapport étroit avec les venues granitiques.

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DISCUSSION FOLLOWING THE PRESENTATION OF THE THREE PRECEDING PAPERS

E. Stensiö remarked that in his opinion it was very unlikely that the *Remigolepis*-layers and arthrodire-sandstone of the Old Red in East Greenland would belong to the lowermost Carboniferous. Apart from the Stegocephalia, the vertebrate faunas of these two series agreed with that of the Upper Devonian in Scotland.

A. Lamont said that no country could claim a stratigraphical standard sequence. The Cowie Beds, near Stonehaven, seemed to fall between the Rudstangen fauna of Norway and the Jelöy fauna. Kjaer and Campbell had associated them closely with the former. This also appeared from Störmer's revision of the invertebrates and from Anatol Heintz's review of the stratigraphy in 1939.

T. S. Westoll (in reply to Dr. A. Lamont): The fauna of the Cowie Harbour (Stonehaven) fish-bed was unfortunately not very well preserved. The invertebrates offered, in fact, very little help towards the detailed determination of their age. The vertebrates were much more useful. Though Dr. White and the speaker might disagree about the generic ascription of the " cephalaspid " *Hemiteleaspis*, it could only be regarded as either a species of *Hemicyclaspis*, or as a slightly less " advanced " form, and in either case an age earlier than Downtonian was highly improbable. The occurrence of *Traquairaspis* and *Phialaspis* was also thoroughly in favour of Downtonian age. Any attempt to institute long-range correlation between Ireland and the Stonehaven area simply on the basis of the existence in both regions of volcanic rocks was a waste of time. In the Downtonian of Stonehaven the tuffs, and the thin lava flow described by Hutchinson, were best regarded as forerunners of the much more important volcanicity of the " Lower Old Red Sandstone." They offered another link between these groups of strata; the Stonehaven Downtonian was best regarded as the basal unit of the Old Red Sandstone sedimentation.

C. J. Stubblefield recalled that Wickham King had been influenced in extending the upward limit of the Downtonian by the recurrence of marine strata up to nearly 2,000 feet above the Ludlow Bone Bed. The speaker suspected that these marine strata were a result of rhythmic deposition of marine and non-marine strata. This factor, he considered, might well influence mapping of the dividing line between Silurian and Old Red Sandstone proposed by Dr. White if that line were taken arbitrarily at the Ludlow Bone Bed and would prove to be important in areas where the Ludlow Bone Bed facies was unrecognized.

He enquired if Dr. White's researches on *Pteraspis* had thrown any light on the age in terms of the Rhineland succession of the *Pteraspis cornubica* occurrences in the Dartmouth Slates of South Cornwall. These pteraspids were large and had a pointed snout resembling that of *P. dunensis*.

E. I. White, in replying to Dr. Stubblefield, agreed that one of the points in Mr. Wickham King's classification of the Downtonian within the Silurian system was the continuation of certain Ludlovian brachiopods into the Temeside series, but he considered that the continuation of such forms as *Lingula* was to be expected, and thus the importance of such a survival was outweighed by the appearance in the Ludlow Bone Bed of important vertebrate genera.

He thought that although an easily mappable horizon was desirable as the boundary between two formations the purely utilitarian aspect must be subordinated to scientific considerations.

The relationships of the fossils referred to *Pteraspis cornubica* were not yet clear: one specimen in the British Museum certainly appeared to have a short rounded snout, quite unlike that of the Siegenian *Rhinopteraspis dunensis*, but it was possible that more than one form was represented.

L. J. Wills spoke of his admiration of Wickham King's pioneer work, but thought that King had been confronted with the difficult, but not uncommon, problem that can arise when the original boundaries of systems do not accord with the results of more up-to-date stratigraphical research. King had in fact added to the Downtonian (the Downton Castle Sandstone of Murchison), which was the summit of his Silurian system, beds that Murchison called Old Red Sandstone. The latter has come to be regarded as Devonian in age, but King believed that most of his red Downtonian and Dittonian were pre-Lower Devonian, and this may well be the case. Here there was a great thickness of strata which was unaccounted for in either Silurian or Devonian as originally defined. King added it to the former. This influenced the usage of the terms Downtonian by the Scandinavians.

E. Stensiö asked whether it was certain that the *Coccosteus* from the Welsh borderlands was a true *Coccosteus*. *Coccosteus* had appeared recently to include two or more different genera.

THE UPPER AND LOWER LIMITS OF THE PLIOCENE*

By A. TINDELL HOPWOOD

Great Britain

ABSTRACT

The metabolism of mammals makes them less sensitive than other animals, whether terrestrial or aquatic, to small environmental changes. Their migrations are so swift that the time factor may be ignored. Hence mammals are well suited for use as guide fossils in making wide correlations. As a rule geological periods are separated by fiducial lines of practical convenience, based on the appearance of immigrant forms. In the Tertiary, the Pontian and Villafranchian contain new faunas; they mark the beginning of the Pliocene and Pleistocene respectively.

WILLIAM SMITH'S dictum, that strata are recognized by their organized remains, has the simplicity of genius, but, as with all generalizations, its detailed application is difficult. The biological sciences tend towards the formulation of neat and tidy classifications which are supposed accurately to reflect the facts as we see them, and also to serve the practical purpose of pigeon-holing our knowledge. Nature, on the other hand, is never static, and knows no sharp boundaries. Whenever we try to achieve the impossible by seeing Nature as a whole, we form a vague impression of a vast and ever-changing pattern, itself composed of an infinity of patterns of lower grades, in which the lights and shades are in a continuous state of flux. The details of the patterns are always dissolving and reforming, wherefore their boundaries are always indeterminate.

In the early days of any science, the highest lights are the first to attract attention; hence the first sketch ignores the shadows and half-tones, because they remain for the time unknown. But, as work proceeds, and knowledge accumulates, the half-tones and shadows force themselves on the attention more and more, until it is realized that the first sketch, with its sharp outlines, was only a very rough approximation. This gradual blurring of the boundaries is the despair of those hard-headed practical men who demand fixed points of departure, and firm foundations on which to build; but the only way in which we can fulfil their wishes is to draw arbitrary, fiducial lines, which are based on general agreement rather than on the pattern of events. At the same time, it is desirable to relate the fiducial line to the natural pattern and, therefore, to begin by analysing the total pattern into patterns of lower grade.

In the early days of Geology, in 1833, Lyell divided the Tertiary into Eocene, Miocene,and Pliocene. Twenty-one years later, Beyrich intercalated the Oligocene, and twelve years after Beyrich, in 1866, Naumann defined the Paleocene. This is the first pattern, a Tertiary of five main divisions based on marine faunas.

In 1842, only nine years after Lyell had published his scheme, Le Play applied the name Pontian to certain deposits in the Black Sea basin, and inaugurated the use of stage names. Some other stage names, in the order of their introduction, are, Astian (de Rouville in 1853), Aquitanian, Helvetian, Tortonian, Plaisancian (all of Mayer-Eymar in 1857), Sarmatian (Suess in 1860), Burdigalian and Vindobonian (both of Depéret, in 1892 and 1893 respectively). This is the second pattern, of smaller and more numerous subdivisions based on marine faunas. Obviously they are directly related to the members of the first pattern since both patterns have a common base.

As time went on, cycles of sedimentation were recognized. They provide a third pattern, which derives entirely from physical agencies, and is, therefore, essentially different from the previous patterns.

*For discussion following the presentation of this and other papers, see p. 64.

Nevertheless, since the fossil remains on which the first two patterns are based are buried in the sediments on which the third pattern is based, all three patterns must in some way be interconnected.

Of the many other patterns involved, two in particular, which we may term the fourth and fifth, must be mentioned. The fourth, itself a major pattern, is the course of evolution of animals and plants; the migrations of floras and faunas form the fifth.

By now it should be clear beyond question that the problem of where to draw the arbitrary lines is immensely complicated, and that to find a solution which shall command general acceptance is not going to be easy. Fortunately the immediate task is limited to the delimitation of the Pliocene, and I propose to consider it solely from the point of view of the practical man, who is working in the field, and who wants a practical method whereby he may determine the position in the geological scale of the rocks he is studying.

In one sense no other way is open to me for, from the zoologist's point of view, the answer is unimportant. When one deals with rapidly evolving groups capable of swift migration, geological periods lose all meaning; they are far too coarse an instrument to be useful. The mammals are just such a group. For our present purposes they may be regarded as having passed through the whole of their history during the Tertiary, and their migrations were so swift that the time involved was negligible by all ordinary geological standards. In both these respects the mammals differ from marine animals, and there is the further difference that, because of their highly specialized metabolism, mammals are relatively insensitive to minor environmental changes. These three reasons make mammals peculiarly suitable for use as guide-fossils, particularly when it is desired to effect correlations over long distances, and it is on that group that the basic correlation of the Tertiary largely depends.

From the Burdigalian to the end of the Vindobonian, the mammalian faunas developed in a quietly normal way. Some genera died out, others came in from more distant parts, and yet others continued to evolve locally; the whole picture is one of gradual, peaceful change. But the Pontian opened with a major faunal break. The following table contains a list of common ungulate mammals arranged to show their distribution in certain European faunas constantly cited in the literature. The faunas are arranged in chronological order, Sansan being the oldest, and Mont Léberon and Pikermi, which are approximately contemporary, the youngest.

There are twenty genera in Table I. If Hostalets be set aside, nine of them do not go beyond the Vindobonian, seven come in with the Pontian, and four pass through from the Vindobonian to the Pontian.

This is substantial evidence of an abrupt faunal break and, when one reflects that *Hipparion* is not only the commonest, but also the most easily recognized of all Pontian mammals, so that it is admirably suited for use as a guide fossil, one might well decide to draw the Mio-Pliocene boundary at the base of the Pontian. The majority of the workers in Britain and Germany do, in fact, adopt this line.

The purely geological pattern, however, yields a different picture. The Pontian was a time of maximum regression. It marked the end of a cycle of sedimentation of which the onset may be traced in the Aquitanian, but which did not really develop until the Burdigalian. Theoretically, therefore, and on purely geological grounds, there is much to be said for the French thesis that the Pontian should be regarded as the end of the Miocene. But, before attempting to decide which of these two views should be adopted, it is well to consider the faunal changes at the top of the Pliocene. There the point at issue is whether the Villafranchian is to be regarded as the top of the Pliocene or the base of the Pleistocene.

During the Pliocene there was a gradual change, probably climatic, which favoured the deer rather than the antelopes, and the former increased at the expense of the latter. Nearly a score of species of deer have been described from the Astian to the Cromerian inclusive, but they are in such confusion that at present it is not practicable to use them for purposes of correlation. For this reason they are omitted from Table II, which is drawn up on the same lines as Table I.

TABLE I

	SANSAN	SIMORRE	LA GRIVE-ST. ALBAN	SAINT GAUDENS	HOSTALETS, CATALONIA (lower)	HOSTALETS, CATALONIA (upper)	MONT LEBERON	PIKERMI
Anchitherium aurelianense Cuvier	×	×	×					
Hipparion gracile Kaup						×	×	×
Ancylotherium pentelicum Gaudry & Lartet								×
Macrotherium grande Lartet	×	×		×	×			
Aceratherium tetradactylum Lartet	×	×						
Aceratherium incisivum (Kaup)							×	×
Brachypotherium brachypus (Lartet)	×	×	×		×			
Dicerorhinus sansaniensis (Lartet)	×		×		×	?		
Dicerorhinus simorrensis (Lartet)		×	×		×			
Dicerorhinus schleiermacheri (Kaup)							×	×
Hyotherium soemmeringi H. v. Meyer	×	×	×	×	×	?		
Listriodon splendens H. v. Meyer	×	×	×		×	?		
Sus erymanthius Roth & Wagner							×	×
Sus major Gervais							×	
Taucanamo sansaniense (Lartet)	×	?						
Taucanamo pygmaeum (Lartet)	×		×		×	×		
Dorcatherium crassum Lartet	×	×		×	×	?		
Palaeomeryx magnus Lartet	×		×					
Palaeomeryx bojani H. v. Meyer	×	×			?	?		
Dicrocerus elegans Lartet		×	×	×	×	×		
Micromeryx flourensianus Lartet	×	×	×		×	×		
Palaeotragus roueni Gaudry							×	×
Helladotherium duvernoyi Gaudry							×	×
Protragocerus clavata Lartet	×							
Protragocerus chantrei Depéret			×		×			
Tragocerus amalthea (Roth & Wagner)							×	×
Gazella deperdita Gervais							×	
Gazella capricornis (Wagner)								×

Note.—For the provisional lists of the upper and lower horizons at Hostalets I am indebted to the generosity of Srs. de Villalta and Crusafont Pairó, as well as to M. Pirlot. The rising Pyrenees tended to isolate Spain from the remainder of Europe and to allow genera to survive there after they had become extinct elsewhere. Parallel instances are known from other parts of the world: compare, for example, the African survival of *Dinotherium* until the middle of the Pleistocene.

TABLE II

	ROUSILLON	MONTPELLIER	UPPER VAL D'ARNO	PERRIER	CROMER
Mastodon borsoni Hays			×	×	
Mastodon arvernensis Croizet & Jobert	×	×	×	×	
Elephas planifrons Falconer & Cautley			×	?	
Elephas meridionalis Nesti			×		×
Elephas antiquus Falconer			×		×
Hipparion crassum Gervais	×	×			
Equus robustus Pomel			×	×	×
Equus stenonis Cocchi			×		
Equus caballus Linnaeus			×		×
Tapirus arvernensis Devèze & Bouillet	×	×	×	×	
Rhinoceros megarhinus Christol	×	×			
Rhinoceros etruscus Falconer			×	×	×
Potamochoerus provincialis (Gervais)	×	×			
Sus arvernensis Croizet & Jobert			×	×	
Sus scrofa Linnaeus					×
Gazella sp.	×	?		×	
Gazellospira torticornis (Aymard)			×	×	
Parabos cordieri (Christol)		×			
Parabos boodon (Gervais)	×	×			
Leptobos elatus (Croizet)			×	×	
Bison priscus Bojanus					×

The majority of the names employed in this table are those commonly found in the usual textbooks and manuals of Geology. *Potamochoerus*, *Gazellospira*, and *Parabos* have been substituted for *Sus*, *Tragelaphus*, and *Palaeoryx* because the latter names are not only wrong, but also misleading.

There are two faunal breaks, one which is very marked, between the Astian and the Villafranchian, and another which is not so pronounced, between the Villafranchian and the Cromerian. The latter is not of the same significance as the former; it is characterized by the disappearance of old types that have persisted from the Plaisancian and Astian, instead of by the appearance of entirely new types. This is why certain workers regard the Villafranchian as ushering in the Pleistocene, rather than as bowing out the Pliocene.

Another school of thought regards the Cromerian as the beginning of the Pleistocene, and includes the Villafranchian in the Pliocene. Various reasons have been advanced in support of this view, but in the end they all resolve themselves into one of two arguments. The first is that the Villafranchian fauna is closer to other faunas whose Pliocene age is not in dispute, and the second that in the Mediterranean basin the Villafranchian can be correlated with the marine Calabrian, which marks the end of a cycle of sedimentation.

From the foregoing discussion it would appear that the faunal pattern and the geological pattern are out of phase, both at the bottom and at the top of the Pliocene, and it therefore becomes necessary to decide which pattern is to be preferred. The geological pattern of cycles of sedimentation is a theoretical concept based on the study of marine deposits; it cannot be applied with any confidence in

areas which are insufficiently explored geologically. On the other hand, it does allow a synthesis to be made of accumulated observations, and produces very valuable results in the hands of academic geologists. The faunal, or zoological, pattern is empirical and applies impartially to terrestrial as well as to marine deposits. Its application calls for no more than adequate collecting and observation in the field, coupled with the ability to recognize a comparatively small number of guide-fossils. Provided these conditions are fulfilled, there is no difficulty in its application, and it was just that factor of ease of application which led to the early formulation of the principle that strata are to be recognized by means of the fossils which are contained in them, whereas the concept of sedimentary cycles is of much later date.

It seems to me that ease of application should be the deciding factor for, despite the amazing progress of the past 150 years, geology is but a stripling. We who live in Europe or North America, especially in Europe, tend to forget that the greater part of the earth's crust is still unexplored by the geologist, and that even where a patch of colour appears on the map, it often means no more than an inference based on a mere handful of specimens obtained in the course of sinking a well, or putting in the foundations for a dam. Under such circumstances the specialist is very little better off than the man in the field, and however much he may deplore arbitrary lines in theory he is bound to apply them in practice.

Accordingly, my preference is for the inclusion of the Pontian in the Pliocene, and the Villafranchian in the Pleistocene. This solution provides reliable guide-fossils, namely, *Hipparion* for the Pliocene, and *Equus* for the Pleistocene; it is also sound theoretically, in that it is dependent on the principles that strata are to be recognized by the fossils contained in them, and that in all faunal studies the appearance of new types is of greater significance than the disappearance of old ones.

THE HIPPARION BEDS ON THE NORTH-EASTERN COAST OF SPAIN

By P. PIRLOT

Belgium

(Given as an introduction to the paper by M. Crusafont Pairó which follows on pp. 33–42. Dr. Pairó was unable to be present personally.)

In the winter of 1947–48 I travelled with Dr. Crusafont Pairó through the region known as the Vallés-Penedés, which is situated immediately west of Barcelona between a littoral chain of high hills and a pre-littoral chain. The basin in between was formed by a slow subsidence which began at the end of the Oligocene. At the same time, continental Miocene deposits were laid down very regularly in that area. Very limited marine transgressions occurred occasionally in the south-east. Small streams have cut deep ravines and exposed the strata fairly well.

In that region, eleven mammalian localities at least were found at different levels. They range from typical Vindobonian to typical Pontian faunas, that is from faunas similar to those of Sansan or La Grive-St. Alban to a fauna like that of Pikermi. The best succession is found in the Penedés, which is the southern part of the basin. Between the villages San Sadurni d'Anoya and Piera it is quite easy to start from a marine Miocene level and to go up, northwards, as far as the Upper Pliocene. The succession is perfectly exposed and continuous for about 8 km. and the total thickness reaches approximately 1,300 m. A typical Vindobonian fauna has been found half-way up in this series, and 300 m. further up, or 75 m. above stratigraphically, *Hipparion* occurs with a Vindobonian association. Between these two deposits a change in the colour of the clay and the occurrence of a very thick conglomerate perhaps indicate the border-line between the Vindobonian and the Pontian. About 450 m. higher up stratigraphically a purely Pontian fauna is found with the same *Hipparion* as in Pikermi. A similar succession exists in other parts of the Vallés-Penedés, although it is not so well exposed. All this tends to prove that there is a definite Lower Pontian level called Maeotic by the Spanish palaeontologists. In these Maeotic beds the faunal association is as follows:—

52 per cent of the genera are common to Maeotic and Vindobonian.
18 per cent are common to Maeotic and true Pontian.
21 per cent are common to Maeotic, Vindobonian, and Pontian.
9 per cent are special to the Maeotic.

The *Hipparion* itself seems to be a rather primitive type, at this Maeotic level. It will be described in detail in a later paper on the European *Hipparion.* This association of archaic with new invading types is perhaps similar to that found in the Siwaliks by Dr. Colbert; similar geographical reasons may account for this. Unfortunately, very little is known, so far, about the Spanish fauna and levels. Dr. Crusafont Pairó and his colleague Dr. de Villalta are continuing their researches in that field.

Contrasting with the Penedés deposits and further to the west, an Upper Pliocene level has been found which contains a new *Hipparion* of exceedingly advanced type. This is now being investigated, but it seems that the deposit is at least Villafranchian.

EL SISTEMA MIOCÉNICO EN LA DEPRESIÓN ESPAÑOLA DEL VALLÉS-PENEDÉS*

Por M. CRUSAFONT PAIRÓ

Spain

ABSTRACT

I. The Miocene succession is complete in the Vallés-Penedés (Spain):—
   (*a*) An important Burdigalian fauna which is rich in characteristic *Pecten* and Sea-urchins.
   (*b*) The Helvetian occurs in the whole Penedés in two different levels.
   (*c*) The Tortonian represented by blue clays is well defined too.
   (*d*) No Sarmatian level exists there: this term can only be used to designate a local brackish facies included in the Vindobonian with *Cerithium pictum*, *Mactra podolica*, etc. But there are important deposits between the so-called Sarmatian and the *Hipparion*-beds.

II. The Continental Miocene is about 1,200 m. thick in the Penedés and about 1,000 m. in the Vallés. The complexity of this system is shown here:—
   (*a*) A Lower Vindobonian in the Penedés has yielded an archaic fauna with *Pseudocyon sansaniensis*, *Listriodon lockarti*, etc.
   (*b*) The Upper Vindobonian in the Penedés contains a typical fauna quite similar to that of Sansan, La Grive, and Steinheim.
   (*c*) A Lower Pontian or Maeotic occurs in continuity with the preceding deposits and contains an archaic *Hipparion* with a Vindobonian association and new forms typical of that level.
   (*d*) The Upper Pontian level occurs in the Penedés with a Pikermi-like fauna.

III. The complicated East European stratigraphy cannot be applied in the Vallés-Penedés. It has been said that no Sarmatian occurs there. In Eastern Europe, the *Hipparion* occurs in the Upper Bessarabian, in the Chersonian, in the Maeotic and the true Pontian and always with similar associations. This fact and its occurrence in very low levels near Istambul has led some authors to emphasize the homogeneity of the *Hipparion* fauna at this time. But in Spain the first *Hipparion* appears in a transitional association, it is an archaic form, and therefore the *Hipparion* fauna can be considered heterogeneous.

EN el mapa geológico de la Península Ibérica, las manchas amarillas del Mioceno ocupan grandes extensiones, formando amplias cuencas en la Meseta Castellana y en las fosas periféricas del Ebro y del Guadalquivir, además de la del valle inferior del Tajo en Portugal. Pero aparte existen también numerosas y pequeñas cubetas especialmente ubicadas hacia el Levante de la península. La pequeña cuenca del Vallés- Penedés, en el extremo nordeste de España, por su reducida extensión y por su misma proximidad a un centro tan importante como es Barcelona en el orden de los estudios geológicos, ha sido con toda seguridad la que más a fondo ha sido estudiada. Por otra parte, su importancia es verdaderamente extraordinaria en cuanto a las conclusiones que pueden extraerse del conocimiento de su estratigrafía. En efecto, el Vallés-Penedés presenta la serie estratigráfica continental completa de todo el Mioceno sin solución de continuidad entre los diversos niveles, con representación fosilífera muy nutrida y característica en todos ellos y con la sola excepción del Burdigaliense continental. Este hecho es insólito en la Península Ibérica y excepcional en toda Europa y en casi la totalidad del Asia, ya que las faunas de mamíferos aparecen perfectamente ligadas entre sí por eslabones intermedios; estas faunas pueden ser, pues, analizadas en su distribución vertical en sucesiones continuas. Ello nos ha movido a dar a conocer una sinopsis estratigráfica y paleontológica de esta cuenca que, si bien es conocida ya de años, ha sido sólo hasta muy recientemente cuando ha proporcionado sus hallazgos más importantes dentro del campo paleomastológico. El estudio

*For discussion following the presentation of this and other papers, see p. 64

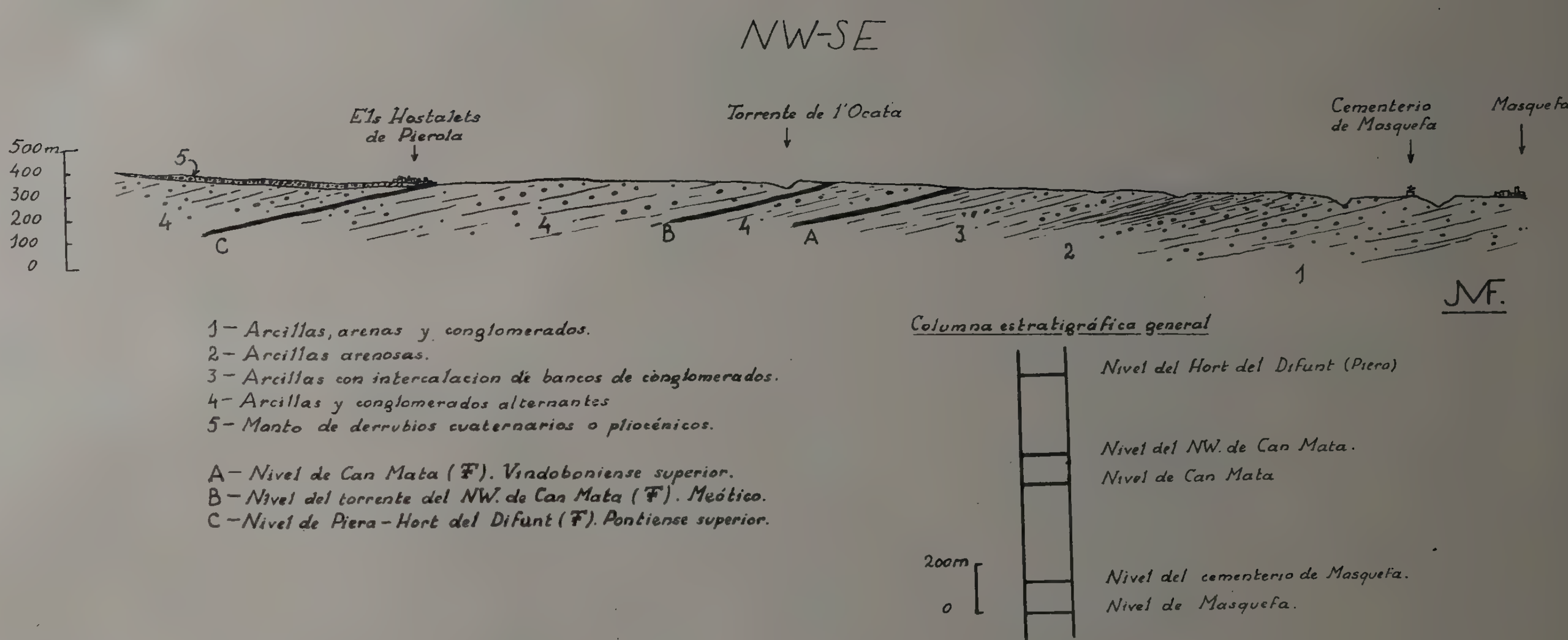

FIG. 1.—*Corte general de las formaciones del Mioceno continental entre Masquefa y Hostalets de Pierola* (*Barcelona*). *Escala* (*vertical y horizontal*) 1 : 20.000.

detallado de estas faunas fosilíferas y su paralelización con las de los yacimientos clásicos, puede coadyuvar al establecimiento de las correlaciones y sincronismos y darnos una luz más orientadora acerca de la cronología de las diversas asociaciones en todo el ámbito eurasiático.

El Canónigo Jaime Almera fué el primero que estudió y determinó los niveles continentales de la depresión del Vallés-Penedés y, aparte del Aquitaniense que se halla desligado de la formación que aquí se estudia, los atribuyó en bloque al Pontiense. Bataller fué quien demostró por vez primera la existencia de niveles vindobonienses en las dos comarcas geográficas de la cuenca (yacimientos de Sant Quirze en el Vallés y de Hostalets de Pierola en el Penedés). Royo y Gomez hizo un afinado estudio de los moluscos terrestres y de agua dulce de la formación y, por ultimo, el firmante con su colaborador Villalta ha ampliado el conocimiento estratigráfico de la cuenca y ha aportado listas mucho más nutridas de mamíferos fósiles. También muy recientemente, y con Truyols, se han dado a conocer las faunas de los niveles bajos del Pontiense y que se han paralelizado con el Meótico de Androussov. Hoy dia, gracias al conocimiento preciso de los niveles y sus correspondientes faunas, el Vallés-Penedés ha cobrado este interés europeo de que antes hemos hablado.

Lo que llamamos " cuenca " del Vallés-Penedés no es en realidad más que una parcela de la denominada Depresión Prelitoral Catalana que se halla situada en el extremo NE. de la Península Ibérica y adosada al antepaís del Ebro, entre la desembocadura actual de este rio y el Pirineo Oriental, formando parte de Los Catalánides de Pacheco y Llopis, tomando el aspecto de un largo surco alineado paralelamente a la costa del Mediterraneo. Esta depresión constituye una fosa tectónica rellenada por sedimentos oligocénicos (Aquitaniense), miocénicos, pliocénicos y cuaternarios, procedentes de la erosión secular de los dos pilares (Cadenas Litoral y Prelitoral) que la limitan. Las fracturas que determinaron su formación, son de edad alpina, fracturas que pueden aún hoy estudiarse en detalle por unos sistemas de fallas alineadas a lo largo de los dos bloques orográficos indicados y que provocaron el remozamiento del senil relieve del macizo herciniano Catalano-Balear constituido, como se sabe, por materiales asaz complejos desde el punto de vista estratigráfico y litológico.

Este alargado surco, que constituye en conjunto una sola unidad geológica, puede dividirse transversalmente en cuatro zonas que fisiograficamente forman otras tantas comarcas geográficas, desde el complejo mesozoico del Montsant (formación montserratina) y Llaveria hasta el Paleozoico de Les Gabarres. Al O., el llamado Campo de Tarragona abierto ampliamente al mar, está formado por una masa de aluviones miocénicos recubiertos en su casi totalidad por un manto cuaternario que ha de dificultar un estudio geológico que está todavía por hacer. Desde el umbral cretaceo de la Sierra de Montmell, hasta el bloque paleozoico del Montseny, se sucede ininterrumpidamente toda la serie estratigráfica desde el Burdigaliense (marino) hasta el Pontiense más alto en la zona que, dividida por la fractura del rio Llobregat, determina la existencia de las comarcas del Penedés y del Vallés. Al O. del Montseny, una debil capa pliocénica recubre el granito casi superficial en el segmento de La Selva. Las dos zonas centrales, que unificamos con el nombre de Vallés-Penedés, atraen por lo tanto nuestra atención con mucho más interés dada su complejidad en el orden estratigráfico y la riqueza paleontológica de sus sedimentos neogénicos.

LA SERIACION MIOCÉNICA

En el Vallés-Penedés encontramos, pues, la máxima representación miocénica, pues los sedimentos, contando con las series marinas y continentales, se escalonan desde el Burdigaliense hasta el alto Pontiense. El primero de estos pisos no ha podido caracterizarse en las zonas continentales y sospechamos que es muy probable su ausencia. Los tramos marinos y continentales se extienden a lo largo de la depresión formando dos bandas paralelas, la primera de las cuales realiza como una especie de cuña, con máxima representación en el Penedés, para terminar estrechándose paulatinamente en el Vallés, no trascendiendo ya más al oeste.

No se han realizado todavía estudios afinados de correlación estratigráfica entre los niveles marinos y los continentales; por el momento, la caracterización de los distintos tramos se ha hecho de manera

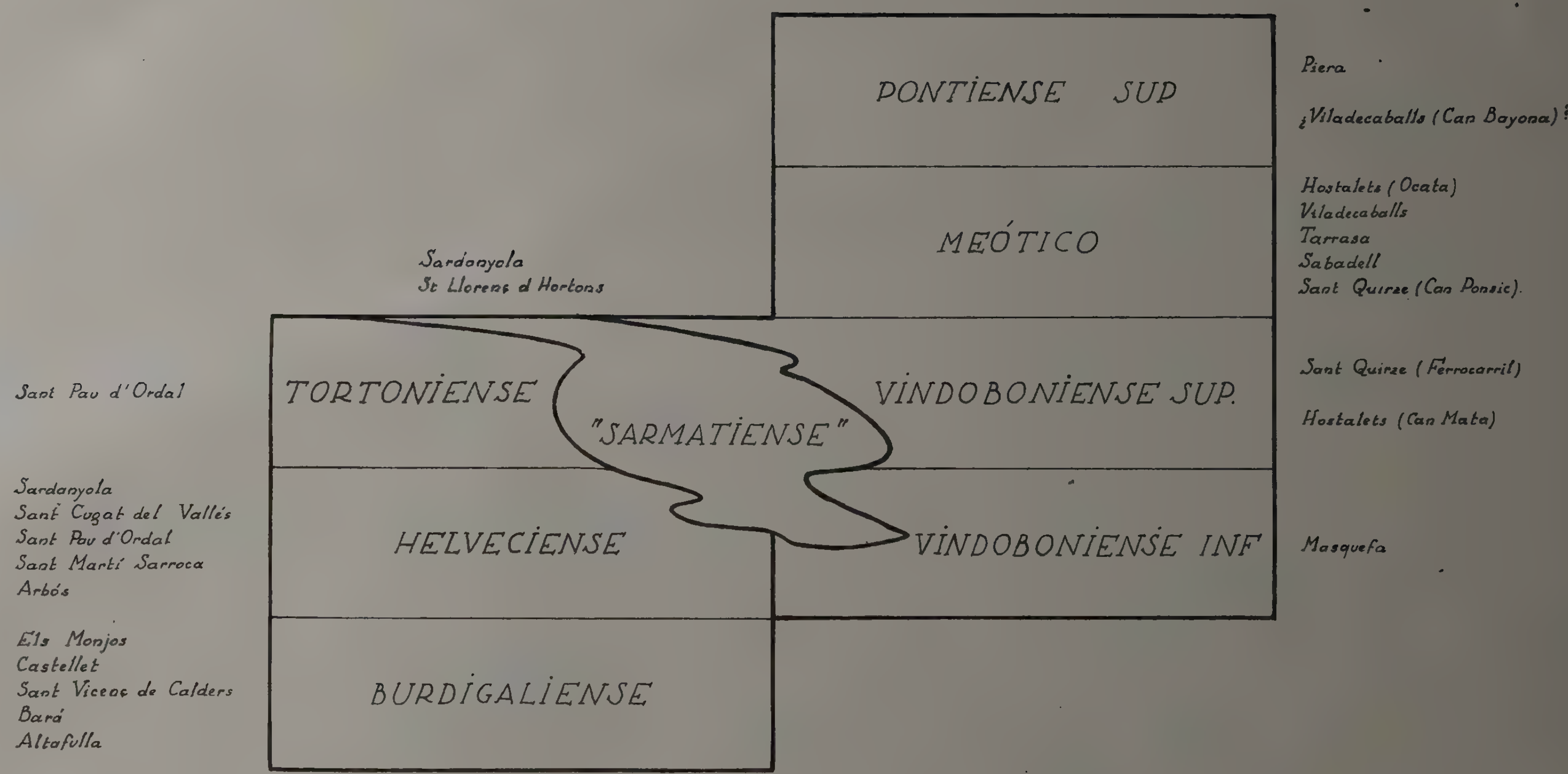

FIG. 2.—*Facies marinas, salobres y continentales en el Mioceno del Vallés-Penedés.*

independiente y atendiendo a las asociaciones faunísticas de ambas zonas. Incluimos, sin embargo, por via provisional, un cuadro representativo y esquemático de estas correlaciones.

(*a*) *Los niveles marinos*

Burdigaliense.—El piso más inferior de la formación marina en la cubeta es el Burdigaliense, representado por potentes bancos de lumaquelas detríticas y extensas hiladas de molasas fosilíferas. Desde los pequeños acantilados costeros (Altafulla, Bará), el Burdigaliense se extiende formando una faja apoyada en el Cretaceo del bloque de Garraf (St. Vicens de Calders, Castellet, Els Monjos). La fauna abundantísima, es especialmente rica en Pectínidos característicos (*Flabellipecten fraterculus*, *Fl. costisulcatus*, *Pecten subbenedictus*, *Chlamys catalaunica*, *Ch. perlaevis*, *Ch. scabrella* var. *tarraconensis*, *Amussium cristatum* var. *badense*) y Equínidos que fueron objeto de varias monografías por parte de Lambert (*Scutella*, *Schizaster*, *Clypeaster*). Escasean los Gasterópodos; en cambio no son raros los Selaceos (*Odontaspis*, *Oxirhyna*, etc.).

Helveciense.—Encima del anterior aparece el Helveciense con un nivel calizo inferior muy potente y otro superior más reducido, formado por lumaquelas con *Venus aglaurae*. La fauna del Helveciense es numerosa y está formada por gran variedad de Lamelibranquios (*Pecten fuchsi*, *Chlamys scabrella*, *Ch. gentoni*, *Ostraea crassissima*, *O. gingensis*, *Venus dujardini*, *Lucina miocaenica* var. *catalaunica*) y bastantes Gasterópodos (*Turritella turris*, *Conus mercatii*, *Rostellaria dordariensis*, *Pereiraea gervaisi*). Este piso ocupa mayor extensión, iniciándose en el Bajo Penedés y llegando hasta el Llobregat (Arbós, St. Martí Sarroca, St. Pau d'Ordal, El Papiol) para morir en el Bajo Vallés (St. Cugat, Sardanyola).

Tortoniense.—El llamado piso tortoniense, que posiblemente representa una facies de profundidad del piso anterior (Gignoux), viene representado por niveles de arcillas azuladas con abundante fauna (*Pleurotoma*, *Rostellaria*, *Cancellaria*, *Murex*, *Nassa*, *Fusus*, *Ancilla*, *Proto*, etc.) bien caracterizada, especialmente en el notable yacimiento de St. Pau d'Ordal que ha proporcionado centenares de especies.

Al reseñar la serie estratigráfica miocénica, Almera describió la presencia del Sarmatiense. En realidad no se trata de un piso característico, como sucede en Europa oriental, sinó de facies marginales salobres con fauna adaptada a estas condiciones. Dichas facies son sincrónicas del Tortoniense y frecuentemente contienen fauna mezclada con elementos de mayor profundidad. Estan constituidas por depósitos costeros de arcillas y arenas con *Cerithium pictum*, *Mactra podolica*, *Ervilia podolica*, etc., en Hortons, Sardanyola y otros puntos. Al introducir el término " Sarmatiense " en la serie estratigráfica, Almera no hacia mas que seguir el criterio de Deperet, para la cuenca del Ródano que colocaba el Sarmatiense inmediatamente por debajo de las capas con " fauna de *Hipparion*." En efecto, en aquel entonces se desconocía la presencia en el Vallés-Penedés de las faunas de mamíferos de Hostalets y de Sant Quirze, y las llamadas capas sarmatienses quedaban inmediatamente en contacto con la pretendida formación pontiense, siendo asi que entre los niveles salobres y los que contienen *Hipparion* existe un potente paquete de estratos de edad claramente vindoboniense. El término " Sarmatiense " ha creado en el Oeste de Europa multitud de equívocos y de confusiones, especialmente al intentar encontrar su paralelo entre la serie continental, y representando en estas regiones una facies y no un piso, creemos que debe eliminarse su uso de la literatura geológica occidental.

(*b*) *Los niveles continentales*

El paquete estratigráfico continental del Mioceno del Vallés-Penedés, ofrece una considerable potencia de sedimentos, señaládose un grosor de unos 1,200 m. en el Penedés y de unos 1,000 m. en el Vallés. Estos sedimentos estan constituidos en general por arcillas y margas de diversos tonos, dominando los rojizos en la primera de dichas formaciones y los amarilloverdosos en la segunda, indicando condiciones ambientales probablemente distintas, cosa comprobada por las faunas. Estas elementos pelíticos alternan con capas de diversa potencia de conglomerados de cantos en general bien rodados de cuarzo, pizarras paleozoicas, calizas mesozoicas y granito. En el borde de la Sierra

VALLÉS - PENEDÉS		EUROPA ORIENTAL	
PONTIENSE	PONTIENSE SUP	DACIENSE PONTIENSE S.STR.	PONTIENSE S. LATU
	MEÓTICO	MEÓTICO	
VINDOBONIENSE	VINDOBONIENSE SUP.	CHERSONIENSE BESARABIENSE SUP	SARMATIENSE
		BESARABIENSE INF. VOLHYNIENSE	
	VINDOBONIENSE INF.	VINDOBONIENSE	
	BURDIGALIENSE		

FIG. 3.—*Estratigrafía comparada del Mioceno del Vallés-Penedés y de la Europa Oriental.*

del Prelitoral, abundan las formaciones de pie de montaña con groseros elementos pizarrosos alternando con débiles capas de arcillas; a veces se hallan potentes depósitos de arcosas. Se señala un buzamiento general de unos 10 grados en dirección aproximada NO.

En los tiempos de Almera se habian supuesto los materiales del Mioceno del Vallés atribuibles al Pontiense en sentido estricto, de acuerdo con los escasos elementos de juicio de que entonces se disponía, mientras que las capas arcillosas del Penedés se señalaban como del Cuaternario. Más adelante, Bataller señala el Vindoboniense en Sant Quirze y Hostalets y el Pontiense en Piera; el resto de los yacimientos del Vallés continuaron figurando como del Pontiense s. str. En aquel momento se disponia de los tales yacimientos como hitos aislados dentro del grueso paquete de sedimentos miocénicos. Pero más adelante, nuestras campañas explorativas nos demostraron que todo el Vallés-Penedés podia considerarse como un enorme yacimiento muy rico en mamíferos y otros vertebrados fósiles, y se supuso que el estudio afinado, tramo por tramo, de las capas podría permitirnos una caracterización precisa de cada uno de los niveles. La seriación más completa nos la ofrece el Penedés, en donde los tramos fosilíferos empiezan en el Vindoboniense inferior en Masquefa y terninan, según las exploraciones actuales, en el Pontiense más alto. En el Vallés, hallamos sólo dos niveles con fósiles, el del Vindoboniense superior y el del Pontiense inferior, del cual haremos amplia referencia más adelante.

Vindoboniense inferior.—En las capas más inferiores de la zona fosilífera del Penedés, hemos supuesto la existencia de niveles que pueden atribuirse a un Vindoboniense bajo por la asociación *Brachypotherium brachypus, Pseudocyon sansaniensis, Listriodon lockarti*, en las inmediaciones de la casa de campo de Can Parellada cerca de Masquefa. Esta fauna ofrece evidentes caracteres arcaicos en comparación con la que seguidamente se le superpone a partir de este pueblo, mientras nos adentramos en la formación. No es posible distinguir solución de continuidad alguna con los tramos que siguen, y la composición litológica es del todo análoga.

Vindoboniense superior.—Una potente serie de estratos, todos ellos fosilíferos, continua la formación miocénica desde Masquefa hasta Can Mata, constituida por gruesas capas de arcillas y margas rojizas abarrancadas en " bad lands," alternando con espesores más o menos considerables de conglomerados poligénicos. Estas capas contienen una riquísima fauna, la más importante de España de este nivel y una de las más nutridas de Europa. La asociación faunística es típica del nivel La Grive-Sansan, Steinheim, Augsburg, etc., es decir de un Vindoboniense terminal. Como formas representativas señalamos: *Sorex pusillus* var. *grivensis, Palerinaceus intermedius, Laphyctis mustelinus, Semigenetta sansaniensis, Albanosmilus jourdani, Pseudaelurus quadridentatus, Sciurus spermophilinus, Cricetodon sansaniensis, Titanomys fontannesi, Dicerorhinus sansaniensis, D. simorrensis, Macrotherium grande, Hyotherium simorrense* var. *doati, Listriodon splendens, Micromeryx flourensianus, Euprox furcatus, Protragoceras chantrei, Deinotherium laevius, Trilophodon angustidens*, etc., además de algunas formas nuevas: *Palaeomeles pachecoi, Ictitherium montadai, Pseudaelurus marini, Cricetodon ibericus, Sivapithecus occidentalis*, etc.

En el Vallés, el yacimiento de Sant Quirze, aunque menos rico es demostrativo también por su fauna casi absolutamente idéntica a la de La Grive Saint-Alban. Aqui hallamos: *Proscapanus sansaniensis, Plesiodymilus chantrei, Martes munki, Mustela larteti, Trocharion albanense, Albanosmilus jourdani, Steneofiber depereti, Monosaulax minutus, Cricetodon helveticus, Glis nitteloides, Anomalomys gaudryi, Dicerorhinus sansaniensis, D. simorrensis, Macrotherium grande, Hyotherium simorrense* var. *doati, Listriodon splendens, Taucanamo pygmaeus, Micromeryx flourensianus, Euprox furcatus Stephanocemas elegantulus, Protragoceras chantrei, Deinotherium laevius, Trilophodon angustidens*, etc. Los sedimentos estan constituidos por arcillas plásticas verdoso-amarillentas a veces con capas carbonosas con *Helix, Glandina*, etc., y casi ausencia de conglomerados.

Meótico.—En el Penedés, a seguido de los niveles del Vindoboniense superior, caracterizados como hemos dicho por una fauna típica, encontramos otra potente serie de estratos con composición litológica igual y perfectamente concordantes con los anteriores y que contienen una fauna especial, interferente entre la del Vindoboniense y la del Pontiense alto. Persisten los elementos arcaicos o

mutaciones de los mismos, mezclados con formas que caracterizan los niveles llamados de "Pikermi." Además es típica la presencia de un *Hipparion* nuevo que es del grupo morfológico *H. gracile-mediterraneus*, pero más primitivo, según los datos todavía inéditos del Sr. Paul Pirlot de Bélgica. Estos niveles se paralelizan con los que en el Vallés se superponen inmediatamente a los de Sant Quirze del Vindoboniense terminal, formando la serie Can Ponsich-Sabadell-Tarrasa-Viladecaballs. Estas capas estan situadas en el Penedés a 200–400 m. por debajo del yacimiento de Piera considerado, segun se verá por su fauna, como del Pontiense s. str. Hallamos aquí la siguiente asociacién: *Monosaulax minutus*, *Cricetodon sansaniensis*, *C. affinis*, *Prolagus oenningensis*, *Titanomys fontannesi*, *Taucanamo sansaniensis*, *Hyotherium soemeringii*, *Micromeryx flourensianus*, *Deinotherium laevius*, etc., con *Crocuta eximia*, *Ictitherium robustum*, *Hipparion* sp., *Dicerorhinus schleiermacheri*, *Aceratherium incisivum*, *Gazella deperdita*, *Progonomys cathalai*, *Tragoceras* sp., etc. Además son características las formas típicas de este nivel: *Sorex pusillus* mut. pontiense, *Palerinaceus* (*Postpalerinaceus*) *vireti*, *Promephitis* nova sp., *Lantanotherium sanmigueli*, *Talpa vallesensis*, *Hispanopithecus laietanus*, etc., muchas de las cuales constituyen " mutaciones " estratigráficas de formas arcaicas.

Pontiense superior.—A las capas que hemos venido denominando meóticas, se suceden en el Penedés, sin solucion de continuidad y también con análoga constitución litológica, o por lo menos con características muy semejantes, los tramos de Piera en donde han aparecido ricas brechas osíferas que han proporcionado una fauna de " Pikermi " típica aunque mucho más pobre en especies. Las formas que se conocen hasta el presente de esta procedencia son las siguientes: *Crocuta eximia*, *Metailurus* sp. (?), *Herpestes guerini*, *Hipparion gracile*, *Aceratherium incisivum*, *Chalicotherium goldfussi*, *Sus erimanthyus*, *Tragoceras amalthea*, *Tragoceras* sp., Sivatérido indet., *Deinotherium giganteum*, *Mastodon pentelici*. Hay que hacer notar que los restos de *Crocuta*, de Antílopes, de Giráfidos y de *Hipparion* se presentan en la misma profusión que en el clásico yacimiento del Atica y con disposición biostratonómica análoga.

El alto Pontiense no nos ha sido posible hasta el presente señalarlo en el Vallés siendo probable que falte. Unicamente en la cima de la formación, un cambio de facies litológica determina unas tramos de arcillas rojas en Can Bayona (Viladecaballs) que contienen *Hipparion* y *Dicerorhinus schleiermacheri* y que quizas algun dia se puedan caracterizar de manera precisa.

CONSIDERACIONES GENERALES

Como habrá podido observarse de la exposición anterior, la seriación de los niveles miocénicos en la depresión del Vallés-Penedés es sumamente instructiva sobre todo por lo que se refiere al establecimiento de un preciso escalonamiento de faunas que se extiende desde el Vindoboniense inferior hasta el Pontiense alto dentro de un mismo yacimiento fosilífero. Este hecho, por encima de todo, tiene un gran valor de aplicación al estudio de los llamados " niveles de *Hipparion* " que por su misma complicación y por el aislamiento en que hasta el presente se habian encontrado, provocaron gran confusionismo respecto de las correlaciones y sincronismos.

Desde la época en que Gaudry describió al detalle la fauna con *Hipparion* de Cucuron, al pie del Mont-Luberon en el bajo Ródano, numerosas localidades han venido a engrosar la lista de los yacimientos conteniendo el conjunto faunístico que acompanña a *Hipparion gracile*. Esta fauna se ha considerado característica de las formaciones continentales que se superponen a los niveles más recientes de la transgresión miocénica. En la cuenca atlántica francesa (Orignac), en España (Concud), En Europa Central (Eppelsheim), en la cuenca vienese (Belvedere), en la panónica (Budapest, Baltavar), en la póntica (Cetatea Alba, en Rumania, Odessa en Ucrania, Kertch y Sebastopol en Crimea, Stavropol en Ciscaucasia, Seteppe Eldar en Transcaucasia), y en la Península Balcanica (Skopleje y Veles en Macedonia, Pikermi y Samos en Grecia, Istambul en Tracia), se ha hallado *Hipparion* y se ha considerado la fauna como pontiense. El nivel clásico ha sido el de Pikermi, en el Atica, cerca de Atenas, pero su fauna es moderna y no idéntica a la de todos los yacimientos europeos con *Hipparion* (ello aparte, naturalmente, del *sello* geográfico). Los yacimientos que contienen la fauna de tipo Pikermi se hallan siempre por encima de los últimos niveles transgresivos miocénicos pero generalmente

despegadas de los niveles continentales con faunas de mamíferos precedentes. En Europa oriental, donde las faunas malacológicas (niveles con *Mactra*), han permitido al parecer precisar con detalle las fases de la regresión, se han establecido una serie de subpisos imposibles de introducir en las formaciones miocénicas clásicas del occidente europeo. Pero en estos niveles, la fauna con *Hipparion* aparece mucho antes del denominado por los géologos rusos, Pontiense en sentido estricto. En general, *Hipparion* aparece (Androussov, 1902), en el Besarabiense superior y así se ha comprobado en Rusia, en Crimea, en Besarabia, en Tracia e incluso en Viena. Con estos datos, parecería que la fauna de Pikermi debe aparecer en Europa en el Besarabiense superior, no desarrollándose hasta el Meótico. Sin embargo, nos parece que se ha abusado del término " fauna de Pikermi " empleándose constantemente como sinónimo de " fauna con *Hipparion.*" Un análisis menos superficial permite afirmar que existen muchas localidades con *Hipparion* cuya fauna, no obstante, ofrece notables diferencias con la de Pikermi, caracterizada quizas por su modernidad y considerada en general como la más típica del Pontiense. Por lo demás, esta fauna, extendida ampliamente por todos los confines mediterraneos en la cima del Pontiense, parece indicar el máximo alcance de la regresión, inaugurando cambios fisiográficos y paleobiológicos en todo el ámbito circumediterraneo, suficientes para considerar, como hacen los autores anglosajones, que ya se ha iniciado el Plioceno. Asi, pues, parece que existiría un nivel con *Hipparion* inferior al de Pikermi (que debería quizas encajarse en el Pontiense s. str. de los rusos), pero la falta de seriaciones contientales completas de todo el Mioceno no ha permitido colocarlo con precisión.

He aqui, pues, que la pequeña cuenca del Vallés-Penedés, ha venido a aportar datos no despreciables al estudio de la cronología de las series miocénicas con el hallazgo de la deseada seriación desde el Vindoboniense hasta el Pontiense alto. Nos encontramos en un caso probablemente único en Europa, en que la fauna de Pikermi (Piera), no aparece despegada de sus substrato, sinó unida mediante faunas intermedias y también con *Hipparion* a la fauna de Sansan-La Grive (Sant Quirze, Hostalets: Can Mata). En el Vallés-Penedés ha sido posible, pues, distinguir sobre el típico nivel vindoboniense superior, otro con elementos faunísticos propios de las capas inferiores o mutaciones de éstos, pero ya con *Hipparion* y otras formas más modernas. Este *Hipparion*, como se ha dicho, es una forma más arcaica que *H. gracile-mediterraneus*. A este último nivel le hemos venido denominando Meótico, puesto que en la seriación de Europa oriental, los geólogos rusos llaman con este nombre al nivel inmediatamente inferior a su Pontiense en sentido estricto y que posiblemente sería sincrónico con el de Pikermi.

Hemos desterrado el término " Sarmatiense " utilizado por algunos autores españoles para designar las capas inmediatamente superiores al Vindoboniense terminal, puesto que el Sarmatiense establecido para la estratigrafia oriental indica precisamente el mismo Vindoboniense superior. Almera utilizó este nombre para designar las facies salobres intravindobonienses a las que no se puede dar la categoría de nivel. En el Vallés-Penedés, pues, así como en el resto de España creemos que no hay lugar para un nivel intermedio entre el Vindoboniense superior y el Pontiense en sentido lato (con *Hipparion*). Hasta hace poco se consideraba el Sarmatiense ruso como falto de *Hipparion* (Gignoux) y de ahí nuestro paralelismo de las primeras hiladas con *Hipparion*, con el Meótico de Androussov. Pero, como se ha dicho, se admite la presencia de este Equido, acompañado además, de su cortejo faunístico, ya desde el Besarabiense superior.

Chaput y Gillet de acuerdo con los hallazgos de Arabu y de Malik y Nafiz, apuntan la idea de que el Besarabiense superior y el Chersoniense deberían quizas unirse al Meótico para entrar dentro del marco del Pontiense lato. Es posible que el cortejo del *Hipparion gracile* aparezca antes en la Europa oriental que en la occidental, pero téngase en cuenta, de otro lado que en el Vallés-Penedés existe un *Hipparion* del grupo filético del *H. gracile* pero más primitivo, inmediatamente por encima del nivel Sansan-La Grive y en un nivel inferior a la fauna llamada de " Pikermi." Ello se paraleliza con la idea de considerar que el *Hipparion* no aparece sinó hasta el Pontiense. Los niveles más inferiores de nuestro Pontiense (el que hemos denominado Meótico y que por ser ahora y en tódo caso demasiado comprehensivo podria bautizarse como Vallesense, si no se quiere utilizar la literatura

estratigráfica oriental), sin embargo, y seguramente por causa de aislamiento geográfico debido a la peninsularidad, contiene una fauna de tipo paleoendémico, aunque enriquecida ya con algunos elementos antecursores del cortejo oriental.

Resumidamente: los hallazgos de Küçuk Cekmece, cerca de Istambul, nos demuestran la presencia de una fauna del " tipo Pikermi " en niveles o tramos bastante bajos estratigraficamente. Ello nos induce a creer en le que dicen Arambourg y Piveteau respecto de la homogeneidad de esta fauna en el tiempo. Pero el hecho de que una asociación de este tipo se halle en el Vallés-Penedés muy por encima de los tramos del Vindoboniense superior, y en un momento en que se anuncia un cambio muy importante desde el punto de vista fisiográfico, nos hace suponer que esta fauna caracteriza *aqui* un Pontiense alto y que representa la fase de la máxima regresión. Si esta fauna es homogenea en el tiempo en las regiones orientales, entonces es muy arriesgado tomar como referencia el nivel de Pikermi como característico del Pontiense alto puesto que la misma asociación se halla ya en el Chersoniense si no antes*.

En España, por el contrario, la sucesión es clara: Vindoboniense superior con fauna del tipo Sansan-La Grive, Meótico o Vallesense con elementos propios paleoendémicos, con un *Hipparion* primitivo y algunos elementos inmigrados, y Pontiense alto con la máxima representación de los elementos orientales que indica la expansión geográfica durante el período tope de la regresión.

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*La dificultad principal para el aclaramiento de esta cuestión tan interesante de los sincronismos estriba, a nuestro modo de ver, en el hecho de tomarse ya sea la fauna continental, ya sea la salobre para el establecimiento de los distintos niveles. Si las condiciones ambientales continentales no han variado, la fauna es homogenea y nos da esta sensación de unidad en el tiempo; si las condiciones salobres han experimentado cambios importantes (progresiva desecación) para producir especies adaptativas, entonces tendremos idea de una heterogeneidad estratigráfica.

THE TRANSITIONAL PASSAGE OF PLIOCENE INTO THE PLEISTOCENE IN THE NORTH-WESTERN SUB-HIMALAYAS*

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India

ABSTRACT

The heavily sedimented tract of country of Hazara-Punjab Sub-Himalayas, with its pile of over 30,000 feet of fluviatile, fluvio-glacial and sub-aerial sediments, contains one of the most complete and copious records of Mio-Plio-Pleistocene. This is a well-bedded and continuous sequence with insignificant local breaks containing, at several horizons, abundant Mammalian fossils to enable a classification into stages. The thesis of this paper is that nowhere in this pile of sediments is a definite natural Pliocene-Pleistocene boundary discernible. The succession in two type areas is described: (i) the Soan Valley syncline and (ii) sections in the Pir-Panjal range in Kashmir, where the ice-age deposits rest conformably over lacustrine deposits containing *Elephas hysudricus*.

This stratigraphic record is unique in being concurrent and synchronous with the tectonic history of the later phases of Himalayan uplift, the onset and progress of the first two glaciations of the Himalayan ice-age, and the development, spread and extinction of the wonderfully prolific Siwalik Mammalian fauna preserved in the beds, abounding in all the higher mammals except Man. Deposition during this interval went on uninterrupted and has preserved a complete register of these interesting events.

THE heavily sedimented tract of country of Hazara-Punjab Sub-Himalayas, with over 30,000 feet of fluviatile, fluvio-glacial and sub-aerial deposits, contains one of the most complete and copious records of Mio-Plio-Pleistocene ages. Of these the Pliocene-Pleistocene is the more fully developed. The region shows a well-bedded and continuous sequence of deposits with only local breaks; at several horizons, the sediments have preserved an abundance of Mammalian fossils which have been thoroughly studied by a band of able palaeontologists, particularly in the last three decades. The thesis of this paper is that nowhere in this great series of sediments, is a definite, natural Pliocene-Pleistocene boundary discernible and that the topmost beds of the Upper Siwaliks fall across the accepted boundary of the Pliocene-Pleistocene of the European standard scale. The passage of the former into the latter is everywhere gradual and transitional and not marked by any regional breaks, either stratigraphical or palaeontological.

The accompanying Table of sequence of stages from Middle Miocene to Middle Pleistocene is broadly accepted by geologists of the Indian Geological Survey who have worked in this field for many years in the systematic survey, mapping, fossil collecting and classifying of this unique sedimentary record. The uniqueness of this stratigraphic record lies in its being synchronous with the tectonic history of the last two uplifts of the Himalayan chain, the onset and progress of the first and second Glacial ages and the development, spread, and extinction of the wonderfully prolific Siwalik Mammalian fauna of the sub-montane plains, abounding in all the higher mammals except Man. Uninterrupted deposition during this interval at many favourable sites has preserved a complete sedimentary register of these interesting events.

The present writer has spent six long field seasons in this area between 1921-31, and has had the benefit of the maps, reports, and literature of the previous workers, Pilgrim (1910-15, 1944), and Cotter (1933). The critical areas, elucidating the conformable passage of the Pliocene into the Pleistocene, in his opinion, are (i) the centre of the Soan Synclinal basin in North-West Punjab and (ii) the summit

*For discussion following the presentation of this and other papers, see p. 64.

belt of the Pir Panjal range (13,000 feet mean altitude) in the Kashmir Himalayas, where are preserved on its wide, gently sloping, north-eastern flank copious deposits of pre-glacial times overlain by beds containing moraines of the earliest glaciation in this region followed by those of successive glaciations.

I. THE SOAN GEOSYNCLINAL BASIN OF TERTIARY RIVER DEPOSITS

In this area of remarkably lucid exposures, overlying the Middle Siwaliks of Dhok Pathan stage (Pontian), is a belt of some 6,000 feet of Upper Siwalik (Plaisancian and Astian) strata containing a richly diversified fauna of *Stegodon ganesa*, *Elephas planifrons*, *Elephas hysudricus*, *Leptobos*, *Boselaphus* aff., passing gradually up into a coarse boulder-conglomerate (with *Equus*, *Bos*, *Elephas*, and *Boselaphus*), containing intermingled moraine material representing the outwash from the terminal moraines of the Pir-Panjal glaciers. On the evidence of contained fossils in the lower part of this series, divided into two stages, Tatrot and Pinjor (the richest mammaliferous zones in the Siwaliks), it is assigned an Upper Pliocene age by Pilgrim, Cotter, and Wadia. The upper, the Boulder-conglomerate stage, is assigned a Lower Pleistocene age both on account of its containing such advanced forms as *Bos* and *Equus* and *Elephas antiquus*, represented in India by *Elephas namadicus*, and its content of glacial debris. The varied assemblage of fossil forms met with in the Tatrot and Pinjor stages is strikingly absent in this stage, a probable explanation being widespread migration or extinction of highly evolved genera of ungulates, carnivores, anthropoids, and proboscideans, brought about by the advent of arctic conditions of the first Glacial. The Boulder-conglomerate stage in turn is succeeded, after a well-marked but minor unconformity, by Sub-Recent fluvio-glacial silts, loess and gravels, full of evidence of human culture of early to middle palaeolithic time. The few minor breaks in deposition noticed at various levels in this 11,000 feet thick Dhok Pathan-Boulder-conglomerate succession do not denote any stratigraphical hiatus; they are of local occurrence only and due to contemporaneous erosion, a common feature in a thick fluvial series laid down during a period of great earth disturbances. Members of the De Terra expedition observing local sections have mistaken them for unconformities. If they had been traced laterally, it would have been found that they disappear or pass into an overlap.

W. D. Matthew (1929), E. H. Colbert (1935), and G. E. Lewis (1937) are inclined, from the affinities of certain Upper Siwalik mammalian genera, to regard the Boulder-conglomerate as of Middle Pleistocene age and H. De Terra (1939) takes a conglomerate beneath the Tatrot stage as denoting a line of unconformity and places the base of the Upper Siwaliks as high up as the standard European datum-line between the Pliocene and Pleistocene (Villafranchian). Apart from the fact that the basal Tatrot conglomerate of his Attock area is an intraformational conglomerate of local occurrence, disappearing laterally, *e.g.*, in the Soan basin, this view has no support from the general facies of the fossil fauna of the Tatrot stage which is, as Pilgrim has shown, considerably older than Pleistocene. Quite a number of species, as well as genera, including *Mastodon sivalensis*, *Hippohyus*, and *Hipparion*, have passed upwards from the underlying Dhok Pathans of Pontian age into the Tatrots, while genera such as *Equus*, *Elephas*, and the higher Bovids are absent.

II. THE PIR-PANJAL GLACIATED AREA OF KASHMIR

This area also possesses critical evidence about the transitional Pliocene-Pleistocene passage. It is separated from the former area by the Middle Himalayan 15,000 feet high Pir-Panjal range. In this area, the relevant deposits, contemporaries of the Upper Siwaliks of the Punjab, designated the Karewa Series, are well exposed and have attracted attention of observers since 1860. The series is composed of well-bedded lacustrine sediments, divided into two stages by a well-defined hiatus. The lower part is composed of over 4,700 feet of thick soft, dark grey, tough clays, shales, and sandstones, with seams of lignite and well-bedded conglomerates (Lower Karewa series) unconformably underlying the Upper Karewas. The last-named group, about 1,000 feet thick, which is entirely glacial in constitution, is according to Middlemiss and the present writer, composed of reassorted deposits of the first Interglacial (and possibly also of the second Glacial) period. That the underlying Lower Karewas

are of Pliocene pre-glacial age, contemporaries of the older stages (Tatrot and Pinjor) of the Upper Siwalik on the opposite side of the Pir-Panjal, is provable by stratigraphic as well as fossil evidence (Middlemiss, 1912; Wright, 1924). The lower limit of this stage, however, is not systematically examined or collected from; it is possible it might reach down to Dhok Pathan level (Pontian). The base of the series rests on folded Triassic and other pre-Tertiary rocks; the shales and sandstones are finely stratified and well-sorted and the inter-bedded conglomerates are likewise in well-defined beds. The whole group is crowded with plant fossils, indicative of mild temperate or sub-tropical climate, with interbedded lignite seams suggesting quiet deposition in the lake which filled the whole valley of Kashmir during the greater part of Plio-Pleistocene. This is particularly marked in the lower conglomerates which are of true colluvial origin, without faceting or striations, etc., which characteristics, on the other hand, are abundant in the conglomerates occurring in upper members of the Lower

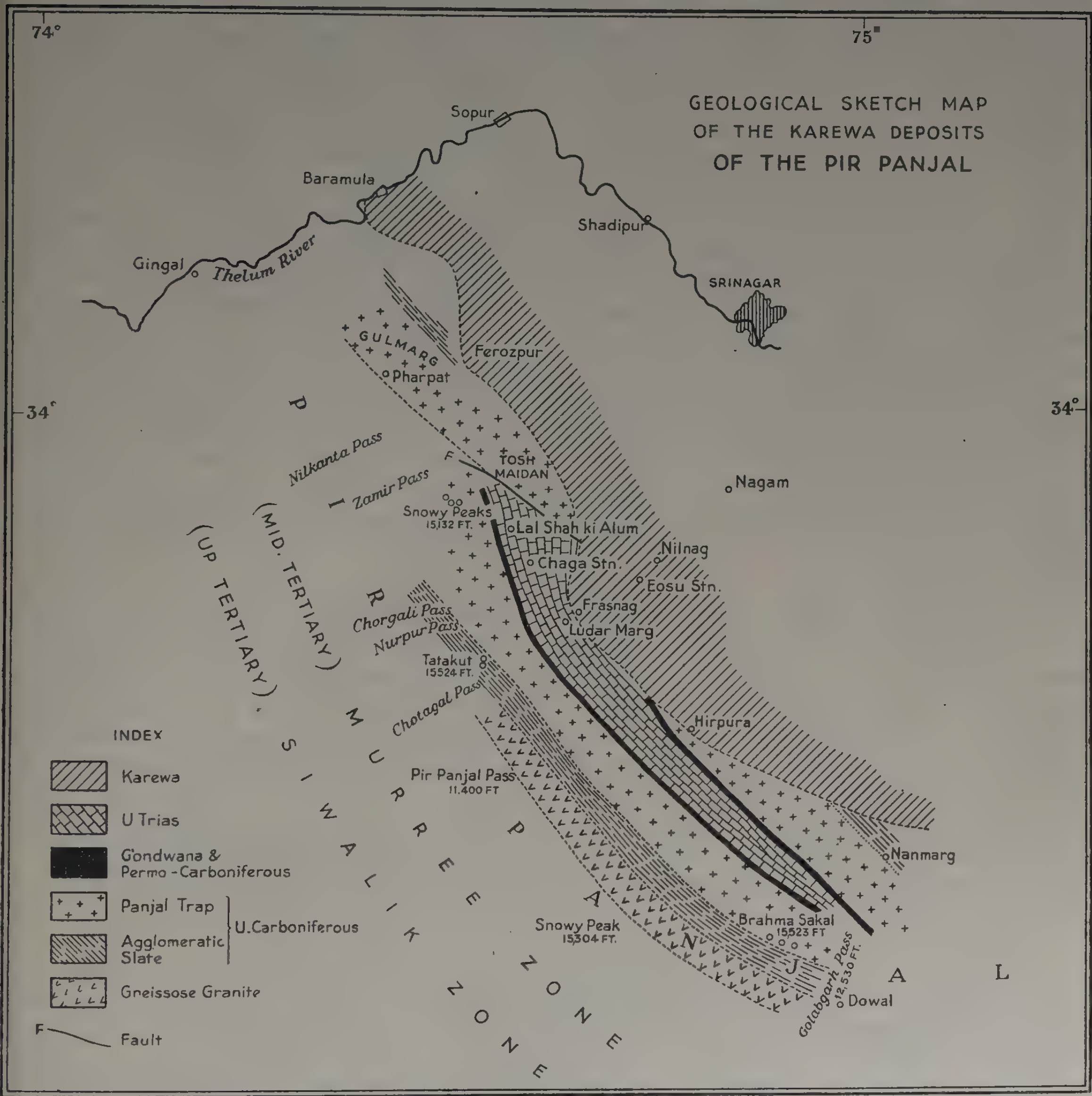

FIG. 1.

Scale: 1 *inch* = 12·13 *miles*. *For Thelum read Jhelum*; *for Chotagal read Chotagali*; *for Nanmarg read Nagmarg.*

Karewa series and in the Upper Karewa beds. It is difficult to draw a line in this 4,700 to 5,000 feet thick Lower Karewa series to demarcate the passage into the Pleistocene glacial beds from the underlying indubitable lacustrine beds. The unconformity which is observed so prominently at the top of the Lower Karewa stage, some 4,700 feet above the base, does denote an important stratigraphical hiatus in the Glacial sequence. But it lies wholly within the Pleistocene and is on the same stratigraphical level as the slight break mentioned above over the Boulder-conglomerate stage of the Soan area. The Upper Karewas are about 1,000 to 1,500 feet of glacial wash of coarse moraines (of the second Glacial) intercalated with sand, varve-clays and marl deposits of the lake which intermittently occupied the Upper Jhelum valley of Kashmir during the Pliocene and Pleistocene.

Fossil evidence, both floral and faunal, is plentiful in the Lower Karewas of Kashmir, though it becomes scarce in the overlying glacial beds. A rich angiosperm flora, consisting of some 122 species belonging to 64 genera which predominate among the fossil vegetation of the Lower Karewa beds, is believed by palaeobotanists to be of sub-tropical habitat. Its modern altitudinal distribution (10,000 to 11,500 feet) is due to subsequent orogenic uplifts of the Pir-Panjal range to the extent of 6,000 to 8,000 feet above its level in the Pliocene, a conclusion that is fully supported by palaeobotanical as well as structural and morphological evidence (Godwin-Austen, 1859; Middlemiss, 1912; Wadia, 1928; and Sahni, 1936). The lignite and abundant well-preserved plant fossils distinctly point to the warm climate of the Pliocene, and the animal remains, of *Elephas hysudricus*, deer, rhinoceros, and bones, teeth and vertebrae of birds, frogs, fishes, etc., obtained from a lower horizon in the Lower Karewas, corroborate this inference. The basal 2,700 feet or so of the Lower Karewas on fossil evidence are thus pre-glacial (Astian to Sicilian) and not, as De Terra has inferred on physical evidence, deposits of the first inter-glacial period. The passage of the warm Pliocene period into the glacial cold of the Pleistocene took place, therefore, in the middle or later part of the Lower Karewa succession. This is clearly discernible in the abundant marginal, terminal, and out-wash moraines of the first and second Glaciations inter-bedded at the top of the Lower Karewas and with the Upper Karewas. We can readily agree with De Terra (1939) that the third and fourth Glaciations of Kashmir were post-Upper Karewa (Upper Pleistocene). The unconformity between the Lower and Upper Karewa is of significance; there is marked discordance of stratification at places due to the erosion of several hundred feet of the former beds from the crests of two well-defined anticlines in which they are folded (first Inter-Glacial).

The Ice Age in Kashmir

The advent of the Glacial age in North-West Himalaya is believed to have been later in post-Pliocene time than in the Alps and in Europe generally (Villafranchian). It also appears to have terminated earlier in these latitudes; thus the Ice Age deposits would naturally occupy a briefer episode in the otherwise extraordinarily voluminous and varied system of deposits of the Pleistocene of India. The commencement of the Pleistocene in India is not, therefore, the important datum-plane it is in the geology of more northerly latitudes and the early records of this period would not be easily separable from the Pliocene.

Dr. H. De Terra has done valuable pioneering work in the complex Ice Age deposits of Kashmir in deciphering a succession of four glacial epochs in the extensive moraine deposits, lake-formed Karewas and river-terraces, but a good deal yet remains to be done in investigating the late Pliocene and early Pleistocene of Kashmir and farther east in the North-West Himalayan piedmont.

III. OROGENY AND TECTONICS DURING THE PLIOCENE-PLEISTOCENE

This period was one of intense orogenic activity in Northern India; it was during this interval that the final and probably the biggest uplifts of the Himalaya took place, during which, to judge from various structural and morphological evidences observed in the Pir Panjal, the Kashmir Himalayas were uplifted from 5,000 to 8,000 feet. The tilting and folding of river- and lake-formed Karewas, with their sub-tropical fossil vegetation, to altitudes up to 11,500 feet afford a rough estimate of the extent of the movements.

GEOLOGICAL STAGES OF PLIO-PLEISTOCENE OF NORTH-WEST SUB-HIMALAYA

		FLUVIAL DEPOSITS OF THE PUNJAB-HAZARA SUB-HIMALAYAS				GLACIAL DEPOSITS IN PIR-PANJAL RANGE—ICE AGE IN KASHMIR			
			Stages		*Fossils*		*Stages*		*Fossils*
HOLOCENE			Recent alluvium, scree, etc.		Living species.		Recent alluvium of the Jhelum.		Modern plant and animal species.
PLEISTOCENE	UP		Newer terraces and gravel caps.	2,500 feet	Proto-Neolithic tools of Man.		Moraines and terraces of *IV. GLACIAL STAGE.*		
			Loess deposits.		Camel, horse, bison, wolf.		*III. GLACIAL STAGE.*		
	MID		Older gravels and terraces.		Acheulian tools plentiful.	KAREWA SERIES UP	Well-bedded sands and clays with boulders and erratics, varve clays. Basal boulder-bed. *II. GLACIAL.*	1,000 to 1,500 feet	Plant fossils locally abundant; many gastropod and other land molluscs.
	LR	UPPER-SIWALIK	Boulder-conglomerate (Villafranchian) stage.	6,000 to 8,000 feet	*Elephas namadicus, Bos, Equus, Camelus, Buffelus.*	KAREWA SERIES LR	Fine buff and blue-grey shales, sands, and gravels, cross-bedded, varve clays. *I. GLACIAL.* Dark, often carbonaceous, shales and sandstones with thick conglomerate beds and lignite seams. *PREGLACIAL.*	4,700 to 5,000 feet	Fossil leaves, fruit and spores of rose, cinnamon, oak, maple, walnut, trapa; diatoms, land-shells. *Elephas hysudricus, Rhinoceros* sp., *Cervus* sp., Schizothoracine fish; bird and ungulate bones, teeth, etc. Sub-tropical lowland plants.
PLIOCENE	UP	UPPER-SIWALIK	Pinjor stage (Astian).		*Elephas planifrons, Elephas hysudricus, Stegodon, Bos, Boselaphus, Hemibos.*				
			Tatrot stage (Plaisancian).		*Leptobos, Hippohyus, Sivatherium, Rhinoceros, Giraffa, Mastodon sivalensis.*		Pre-Tertiary.		
	MID	MID-SIWALIK	Dhok Pathan stage (Pontian).	4,500 feet	*Mastodon, Hippopotamus, Merycopotamus,* large giraffoids, *Teleoceras, Listriodon.*				
	LR		Nagri stage.		*Dinotherium, Prostegodon, Hipparion, Dryopithecus* and other anthropoids.				

The same conclusion is suggested by the Soan Valley sections. There the Dhok Pathan and Upper Siwalik almost up to the Boulder-conglomerate stage are folded vertically, from which horizon upwards there is a gradual decrease in the amount of inclination of the overlying beds to the almost horizontal Upper Pleistocene gravels of the Rawalpindi area. Here every stage is well-dated from *Hipparion* to *Equus* and *Dinotherium* to *Elephas* and man's advent and occupation of the stage is well documented by abundant pre-historic tools marking various levels of his culture. An important chapter in the tectonic and orogenic history of the Upper Tertiary in India is preserved in the Pliocene-Pleistocene rocks on either side of the Pir Panjal range which yet shows no important break or disconformities. The successive orogenic upheavals, instead of interrupting sedimentation, seem to have accentuated it in the sub-montane troughs which were being formed *pari passu* with the rising mountains.

The observed succession of fossil Elephants in the Upper Siwaliks (Pliocene) and Pleistocene of India is:—

Mastodon cautleyi	Lower Pliocene.	
„ *sivalensis*	Middle „	Tatrot stage.
Elephas (*Stegodon*) *clifti*	„ „	„ „
„ („) *bombifrons*	„ „	Pinjor „
„ („) *insignis*	Upper „	„ „
„ („) *ganesa*	„ „	„ „
„ *hysudricus*	„ „	„ „
„ *planifrons*	Lower Pleistocene	B.-congl. stage.
„ *namadicus* (= *E. antiquus* of Europe)	Middle „	„ „
„ *primigenius* (mammoth)	Middle to Upper Pleistocene	Plateau gravels.
„ *maximus* (living elephant)	Sub-Recent and Recent.	

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LES LIMITES ET LES CORRÉLATIONS DU QUATERNAIRE AFRICAIN *

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RÉSUMÉ

L'auteur, tenant compte de la classification du Quaternaire africain adoptée en 1947 par le Congrès de Nairobi, indique que l'étude des faunes fossiles des gisements nord-africains permet d'établir certaines corrélations stratigraphiques entre les deux régions.

Un niveau repère très important parce qu'il s'étend à tout le bassin méditerranéen est fourni par les couches rouges éluviennes à industrie levalloiso-moustérienne postérieures à la dernière plage soulevée de la mer à *Strombus bubonius*, et contemporaines de la régression marine Würmienne elles correspondent au dernier grand Pluvial et équivalent au début du Gamblien. Certains autres termes du Quaternaire africain sont représentés par divers gisements: ceux de Palikao et du Lac Karâr correspondent au sommet du Kamasien inférieur; celui de Tihodaïne (Sahara) au Kamasien supérieur. La série des grès sublittoraux du Maroc avec le poudingue de base à *Archidiskodon* cf. *recki* englobe tout le Kamasien. D'autre part l'étude des gisements villafranchiens constantinois poursuivie par l'auteur depuis plusieurs années, lui a montré qu'ils équivalaient, par leur faune, à ceux du Kaguérien dont ils renferment l'association caractéristique: *Anancus*, *Elephas* cf. *planifrons*, *Stylohipparion*, *Libytherium*, etc., et devaient, par conséquent être intégrés à la base du Pléistocène; leur équivalance stratigraphique avec ceux du Villafranchien d'Europe justifie l'opinion de Haug, faisant débuter le Quaternaire avec l'apparition des genres modernes *Bos*, *Equus*, et *Elephas*.

LES études comparatives que je poursuis depuis plusieurs années sur les faunes de Mammifères du Pliocène et du Pléistocène d'Afrique me permettent d'apporter aujourd'hui une contribution à la solution d'un des problèmes mis à l'ordre du jour par le Congrès géologique, celui de la limite de ces deux formations, ainsi qu'à celui des corrélations du Pléistocène de ce Pays.

C'est en Afrique orientale que, grâce au développement des anciennes formations lacustres, le Quaternaire offre à l'étude les séries les plus complètes et les plus remarquables par l'association, aux différents niveaux, d'industries humaines et de faunes fossiles. Aussi la classification du Quaternaire, telle qu'elle a été adoptée par le Congrès Pan-Africain de Nairobi, en 1947, offre-t'elle la meilleure et la plus solide base de discussion.

LE PLÉISTOCÈNE DE L'AFRIQUE ORIENTALE

Je rappelerai que cette classification, fondée sur les travaux de Wayland, de Leakey, de Solomon, de Kent, comprend les terrains suivants:—

(1) Les plus anciens dépôts, formés après les grands effondrements du Rift Valley et qui correspondent au premier grand Pluvial africain, constituent l'étage Kaguérien.

A ces dépôts se trouve associée, en certains points, une industrie humaine, plus primitive que les plus vieilles industries chelléo-acheuléennes à bifaces d'Eurasie, l'industrie Kafuenne qui consiste en simples galets de rivière grossièrement éclatés par percussion à l'un des bords, de manière à y déterminer un tranchant ou une pointe.

Ces dépôts contiennent également une faune tout à fait caractéristique dont les gisements se trouvent disséminés depuis le Sud de l'Abyssinie jusqu'au Tanganyika. Les principaux sont ceux de la Vallée de l'Omo (Abyssinie), de Kaiso (Lac Albert), de Kanam (Lac Victoria), de Laetolil (Tanganyika). Leur faune est caractérisée par une association remarquable d'éléments à affinités tertiaires et d'éléments plus récents. Biogéographiquement, l'ensemble est typiquement africain et endémique, mais avec

*For discussion following the presentation of this and other papers, see p. 64.

certains rapports asiatiques incontestables. Les éléments anciens de cette faune sont: un Chalicothéridé, un Dinothérium (*D. bozasi*), un Mastodonte du genre *Anancus*, des Eléphants primitifs (*Archidiskodon* cfr. *planifrons* et *A. Recki*—voison d'*A. meridionalis* et d'*A. hysudricus*—), un Equidé tridactyle du genre typiquement africain *Stylohipparion*, un Sivathériné (*Sivatherium*), un Machairodontidé (*Homotherium*). Les éléments récents sont: des Zèbres, l'Hippopotame amphibie, une Girafe, des Suidés (Phacochère, Potamochère) et divers Ruminants de genres africains et parfois d'espèces actuelles.

(2) A cette première série de dépôts font suite ceux de l'étage Kamasien inférieur qui correspond au deuxième pluvial africain. Lorsque cette nouvelle série sédimentaire se trouve en contact avec la précédente, on constate, entre elles, soit des discordances de stratification, soit des ravinements qui sont l'indice d'une phase de régression lacustre correspondant à une période interpluviale sèche.

Les dépôts du Kamasien inférieur, dont le Ravin d'Oldoway, au Tanganyika, offre une remarquable coupe, renferment, dès la base, une industrie primitive de bifaces, ou coups-de-poing, dont certains sont encore très grossiers, qui se rattache sans conteste au groupe des industries abbevillo ou chelléo-acheuléennes. La faune fossile qui accompagne cette industrie diffère de celle du Kaguérien par la disparition d'un certain nombre d'éléments archaïques tels que: *Anancus*, *Stegodon*, *E.* cfr. *planifrons*, *Chalicotherium*, *Homotherium*. Le reste de la faune persiste encore et passe dans les niveaux supérieurs; elle persiste même en partie dans la série sédimentaire suivante qui constitue le Kamasien supérieur et où elle s'enrichit d'autres éléments à affinités plus récentes.

Dans les niveaux supérieurs du Kamasien inférieur, la primitive industrie de la base passe progressivement à une industrie acheuléenne typique et qui ne diffère en rien de son homonyme d'Europe.

(3) Les dépôts du Kamasien supérieur sont séparés des précédents par ceux d'une phase inter-pluviale sèche qui, à Oldoway, se manifeste sous forme d'une couche rubéfiée, latéritique, qui constitue le niveau III.

Dans le Kamasien supérieur, l'industrie acheuléenne continue à évoluer suivant les mêmes modalités qu'en Europe et plusieurs niveaux successifs ont pu, de ce fait, y être distingués.

(4) Enfin, après une période interpluviale de régression lacustre et d'érosion ou de ravinements des dépôts précédents, une nouvelle période de grandes précipitations atmosphériques amène les dépôts transgressifs du Gamblien.

L'industrie chelléo-acheuléenne s'y trouve remplacée par les industries d'éclats et de lames de type moustérien et paléolithique supérieur (Capsien), dont les techniques reproduisent identiquement celles d'Europe.

La faune associée ne contient plus que des éléments actuels ou sub-actuels: tous les types archaïques des périodes précédentes en ont définitivement disparu.

Aucune autre région du Monde ne présente une série pléistocène aussi continue et aussi complète et, actuellement, le problème à élucider est celui des corrélations entre les différents termes de cette série et ceux de la chronologie plio-pléistocène d'Eurasie.

C'est par l'étude des formations continentales de l'Afrique méditerranéenne, du Sahara et du Soudan, que l'on pourra vraisemblablement découvrir de proche en proche les correspondances stratigraphiques qui nous manquent pour le moment.

Dès maintenant, toutefois, les comparaisons entre divers gisements nord-africains et ceux de l'Afrique orientale permettent de jeter quelques jalons importants.

LE QUATERNAIRE DE L'AFRIQUE DU NORD

Tout d'abord, il est très remarquable de noter qu'en Afrique du Nord (ainsi d'ailleurs que dans tout le bassin de la Méditerranée) et en Afrique orientale, l'apparition des industries moustéroïdes et, un peu plus-tard, de celles de type paléolithique supérieur (Aurignacien-Capsien), coïncide avec le dernier grand changement climatique qui précède l'établissement des conditions actuelles: la glaciation würmienne, d'une part, et le dernier grand Pluvial africain, de l'autre, ces deux phénomènes n'ayant

ESSAI DE CORRÉLATION DU QUATERNAIRE D'AFRIQUE ET D'EUROPE

		Phénomènes climatiques	Industries	Afrique orientale	Sahara	Maroc	Algérie Tunisie	Europe
HOLOCÈNE		Climat actuel Fluctuations postpluviales	Néolithique Mésolithique	**Nakurien** **Makalien**	Cuvettes alluviales	Surfaces et grottes		Remblayage des vallées **(Flandrien)**
PLÉISTOCÈNE	Supérieur	4ᵉ PLUVIAL	Paléolithique supérieur —— Moustéro Levalloisien	**Gamblien** (*Oldoway V*) (*Gilgil river*, etc.)		Grottes et foyers —— Couches rouges méditerranéennes		**Würmien**
		Interpluvial	?				Basses terrasses marines **(Tyrrhénien)** et fluviatiles (*Le Kef*)	
	Moyen	3ᵉ PLUVIAL	Chelléo-	**Kamasien supérieur** (*Olorgesailie*) (*Oldoway IV*)	*Tihodaïne*	Grès de *Rabat* et de *Casablanca*	(*Lac Karâr*) (*Palikao*)	**Rissien**
		Interpluvial		(*Oldoway III*)			Moyennes terrasses marines **(Milazzien)** et fluviatiles	
		2ᵉ PLUVIAL	Acheuléen	**Kamasien inférieur** (*Oldoway I-II*)			?	**Mindélien**
		Interpluvial				Poudingue de *Salé*	Hautes terrasses, etc.	**(Sicilien)** (*Cromer*, etc.)
	Inférieur	1ᵉʳ PLUVIAL	Kafuen	**Kaguérien** (*Omo*, *Kaiso*, *Kanam*, *Laetolil*)			Villafranchien (*St. Arnaud*) (*Ichkeul*)	**(?Günzien)** (*Val d'Arno*) (*Perrier*, etc.)
PLIOCÈNE							Astien	

vraisemblablement qu'une même cause, l'augmentation de l'intensité de l'évaporation marine équatoriale et de la pluviosité générale consécutive.

Au point de vue paléontologique on peut noter que, dans l'une et l'autre région, la faune de cette époque est typiquement africaine et actuelle ou sub-actuelle; mais, cependant, pour ce qui concerne l'Afrique du Nord, à ce fonds africain formé de Zèbres, Eléphants (*Loxodonta atlantica*), Rhinoceros blanc, Hippopotame amphibie, Phacochère, Antilopes et Gazelles diverses, *Lycaon*, Hyène tachetée, Panthère, Lion, etc. . . . s'ajoutent, à ce moment, certains éléments immigrés d'Eurasie qui s'y mélangent temporairement. Ce sont essentiellement des Cervidés (*C. elaphus* et *Megaceroides algericus*), le Mouflon, des Ours (*U. larteti*), le *Rhinoceros mercki* et des Eléphants du groupe de *namadicus* (*E. iolensis*); ils sont, comme je l'ai indiqué ailleurs (Arambourg, 1947) les seuls éléments européens qui, avec les Boeufs et les Sangliers, probablement immigrés d'Asie en même temps que le Buffle antique à la fin du Pliocène, fassent partie de la faune africaine, et ils demeurent d'ailleurs confinés aux régions méditerranéennes sans dépasser, au Sud, la barrière atlasique et saharienne.

Cette faune, avec les industries moustéroïdes qui l'accompagnent au début, se rencontre dans tous les dépôts continentaux immédiatement superposés aux dernières plages soulevées de la mer à *Strombus bubonius*, ainsi que dans le remplissage profond des grottes de la même époque; ces dépôts sont généralement des formations éluviennes fortement rubéfiées, caractéristiques d'un intense ruissellement sous un climat chaud, et que l'on observe tout le long du littoral, dans la situation stratigraphique qui vient d'être indiquée, depuis les côtes atlantiques au Sud du Maroc jusqu'à celles de Syrie*. Ces " couches rouges," avec leur faune et leur industrie caractéristiques, se sont formées pendant la grande régression marine würmienne depuis longtemps reconnue sur tout le pourtour du bassin méditerranéen†; elles constituent, dans tout ce dernier, un niveau repère absolument constant et de toute première importance qui correspond au début du Gamblien de l'Afrique orientale.

Les correspondances stratigraphiques entre les autres termes du Quaternaire de l'Afrique du Nord et ceux de l'Afrique orientale sont plus difficiles à établir. Il faut d'abord noter que, jusqu'à présent, ni le Sahara, ni les régions de l'Atlas, des Hauts Plateaux ou du Tell n'ont livré de gisements qui renferment *in situ* les plus vieilles industries de type Kafuen. Parmi les rares stations où il a été possible d'observer associées une faune et une industrie, comme dans le gisement alluvionnaire de l'Erg de Tihodaïne, au Hoggar, dans ceux de Palikao et du Lac Karâr en Algérie, ou dans celui du Kef en Tunisie, récemment découvert par Dumon, l'industrie est de type acheuléen évolué, parfois terminal (le Kef); leur faune est typiquement africaine et sub-actuelle.

Le gisement de Palikao renferme notamment: *Loxodonta atlantica*, le Zèbre mauritanique (*E. mauritanicus*), le Rhinoceros blanc (*A. simus*), la Girafe, un Chameau (*C. thomasi*), diverses Antilopes (*Connochaetes*), *Alcelaphus*, *Oryx*) et Gazelles, le *Bos primigenius*, l'Hippopotame amphibie, un Phacochère (*P. africanus fossilis*), un Machairodontidé, la Hyène tachetée. L'outillage associé est relativement rare, il est fait d'un grès assez grossier qui se prête mal à la taille et donne des pièces de type acheuléen assez frustes.

Le gisement du Lac Karâr, près de Tlemcen, renferme les mêmes éléments fauniques principaux (sauf *Machairodus*) que le précédent; l'industrie, abondante et très belle, est de type chelléo-acheuléen évolué; elle comprend des bifaces amygdaloïdes et des hachereaux. Ces deux gisements, dont le premier est probablement un peu plus ancien, correspondent sans doute à la fin du Kamasien inférieur et au début du Kamasien supérieur.

Au Sahara, le gisement de l'Erg Tihodaïne, dû au remplissage alluvionnaire d'une ancienne cuvette marécageuse, est remarquable par sa richesse. L'industrie à bifaces, où abondent les hachereaux, est de type acheuléen évolué et rappelle, d'une façon saisissante, celle d'Olorgosailie, au Kénya. La faune renferme une majorité d'éléments africains sub-actuels, auxquels il faut ajouter *Bos primigenius* et un grand Eléphant identique à celui des gisements kamasiens de l'Afrique orientale, *E.* (*Archidiskodon*) *recki*.

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* cfr. Arambourg. Congrès Pan-Africain de Nairobi, 1947 (sous presse).

† cfr. M. Boule, 1906. Les Grottes de Grimaldi. C. Arambourg, 1935. La Grotte de la Carrière Anglade à Guyotville.

Ces caractères fauniques et la similitude des industries permettent d'attribuer le gisement de Tihodaïne au Kamasien supérieur.

Il n'a pas été jusqu'ici question du Pléistocène marocain car ses horizons les plus anciens, ceux à industrie abbevillo-clactonienne des environs de Casablanca, n'ont fourni que très peu de faune caractéristique; toutefois, à Salé, près de Rabat, un niveau de poudingues, qui représente vraisemblablement la base de ces formations, a livré des restes d'un grand Archidiskodonte probablement identique à *A. recki.** D'autre part, la situation stratigraphique de ces gisements et leurs industries permettent de situer leur début à la base du Kamasien. Les travaux de Neuville et Ruhlmann (1941) ont montré, d'autre part, que le reste de la puissante série des " Grès sub-littoraux " de la côte marocaine correspondait aux divers épisodes successifs du Pléistocène moyen. Près de Rabat, la faune de la partie moyenne de ces grès ne contient que des éléments africains tropicaux sub-actuels auxquels se trouve associé *Bos primigenius*; c'est l'équivalent de celle de Palikao et l'on peut attribuer cette formation au Kamasien supérieur. Il est intéressant de noter que c'est à ce niveau qu'ont été découverts les restes de l'Homme de Rabat, dont les caractères néanderthaloïdes s'allient à quelques traits archaïques.

De cette rapide revue il est donc possible de conclure que, jusqu'ici, on ne connaît en Afrique du Nord, ni dans les régions méditerranéennes, ni au Sahara, aucun gisement préhistorique à industrie Kafuenne en place. Mais, par contre, certains gisements paléontologiques de cette contrée peuvent fournir, comme je l'ai montré ailleurs, d'importantes indications sur les corrélations stratigraphiques générales et sur le début du Quaternaire.

LE VILLAFRANCHIEN NORD-AFRICAIN

On connaît depuis longtemps, sur les plateaux constantinois de la région de Sétif, l'existence de vastes dépôts lacustres et alluvionnaires considérés, en raison de leur faune, comme appartenant au Pliocène supérieur (Villafranchien). De nouvelles recherches, poursuivies par moi-même depuis plusieurs années dans ces formations aux environs de Saint Arnaud, m'ont appris que l'on y retrouvait une association faunique identique à celle du Kaguérien de l'Afrique orientale: Mastodontes (*Zygolophodon* et *Anancus*), *Archidiskodon* cfr. *planifrons*, *Ar.* cfr. *recki*, *Stylohipparion*, *Libytherium*,† *Giraffa*, *Hippopotamus amphibius*, Zèbre (*E. numidicus*) et divers Bovidés de type africain. L'attribution au Villafranchien de ces formations était, jusqu'ici, uniquement fondée sur leur faune qui rappelle, en effet, par la présence des genres *Archidiskodon*, *Anancus*, *Equus*, celle du Val d'Arno, mais sans qu'aucune précision stratigraphique puisse confirmer cette attribution. Une découverte récente, faite en Tunisie par Dumon et Laffitte (1948), vient combler cette lacune: sur les bords de la Garet Ichkeul, près de Bizerte, le Pliocène inférieur marin, bien daté par une abondante faune de Mollusques, passe progressivement à des couches concordantes sub-continentales de sables et de poudingues renfermant des Vertébrés. L'ensemble a été soumis postérieurement au dépôt des dernières couches, à des mouvements tectoniques qui ont redressé le tout presque à la verticale; dans toute la région, d'autre part, les derniers mouvements tectoniques marquent la fin du Pliocène. Les couches de l'Ischkeul, post-plaisanciennes, peuvent donc être attribuées raisonnablement, du point de vue stratigraphique, à la fin du Pliocène, c'est-à-dire au Villafranchien. Or la faune de Mammifères de ces couches renferme les éléments suivants: *Anancus osiris*, *Archidiskodon* cfr. *planifrons*, *Stylohipparion*, *Atelodus* aff. *simus*, *Libytherium*, et divers Bovidés (*Redunca*, *Gazella*, etc. . . .). Ce ne sont là que les premiers éléments recueillis, car je n'ai encore pu effectuer qu'une prospection sommaire de ce gisement dont l'exploitation systématique sera entreprise prochainement, mais ils suffisent pour démontrer le parallélisme de cette faune et de celle du " Villafranchien " constantinois, dont l'âge se trouve ainsi confirmé. Une seule restriction serait à faire: à l'Ichkeul, je n'ai pas encore trouvé d'Equidés monodactyles associés à *Stylohipparion*, tandis que dans la faune des plateaux sétifiens les premiers abondent et le second y est beaucoup plus

*C'est le spécimen que j'ai décrit sous le nom d'*A. meridionalis* aff. *cromerensis*.

†Ce genre est un grand Sivathériné aux ramures moins ramifiées que celles du *Sivatherium*.

rare. Peut-être l'Ichkeul correspond-il à un horizon un peu plus ancien, au début, par exemple, du Villafranchien, et Saint Arnaud à un niveau un peu plus élevé.

Quoi qu'il en soit, l'analogie des faunes de ces gisements et de celles du Kaguérien de l'Afrique orientale est évidente. Tous les dépôts qui les renferment se sont formés au cours d'une grande période de ruissellement et d'extension lacustre, c'est-à-dire d'un grand Pluvial. Toutes ces raisons militent donc—malgré l'absence en Afrique du Nord d'industrie Kafuenne dans ces gisements—en faveur de leur synchronisme et de l'équivalence stratigraphique du Kaguérien et du Villafranchien nord africain.

La question demeure de savoir si le Villafranchien d'Italie et du Plateau Central de la France correspondent chronologiquement à celui de l'Afrique du Nord et si, par suite, en Europe comme en Afrique, la limite entre le Pliocène et le Quaternaire doit se situer à la base de cet étage. Je ne suis pas éloigné de le penser, étant données les précisions stratigraphiques apportées par le gisement de l'Ichkeul, et ainsi se justifierait l'opinion de Haug faisant coïncider le début du Pléistocène avec l'apparition des genres *Bos*, *Equus*, *Elephas*, ainsi qu'avec la première glaciation; on pourrait y ajouter, en tenant compte des données africaines, " et avec l'apparition de l'*Homo faber*."

Le tableau suivant résume les corrélations du Quaternaire telles qu'on peut les envisager à la suite de ces observations.

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THE BECERRA FORMATION (LATEST PLEISTOCENE) OF CENTRAL MEXICO*

By A. R. V. ARELLANO

Mexico

ABSTRACT

This formation was named by Bryan and Arellano (1946) after the Creek Becerra, between the towns of Tacubaya and Mixcoac on the south-western edge of Mexico City. At Ciudad Deportes this formation, in alluvial-fan facies, is apparently over 16 m. thick, but is difficult to separate from the overlying Noche Buena formation and its base was not found. The riparian facies is here represented by the Armenta Horizon (or 2,242 m. beach), elsewhere called Risco by H. De Terra, who found therein an obsidian artifact. Several kilometres upstream, as in most of the valleys descending into the Mexico City Basin, the Becerra formation is easier to identify, because it overlies a distinctive fossil soil (the Tacubaya), but does not reach the thickness which it shows at Ciudad Deportes, either in the alluvium or in the aeolian deposits.

The normal lacustrine facies is a fine silt, 1 to 4 m. thick, with layers of fine ash and sand, peat, and diatomite, with good pollen content where unaffected by prolonged weathering.

In Tequixquiac, the best-known Pleistocene vertebrate locality of Mexico, the Becerra is developed as several metres of alluvial sands and gravels rich in bones. Early workers (Cope, Freudenberg, and also G. S. A. chart, 1941) dated the contained fauna from Pliocene to early Pleistocene. Bryan and Arellano (1946) assigned a late Pleistocene age to this fauna. H. De Terra has substantiated this by lake history and local glacial evidence, while P. B. Sears, in preliminary results of pollen analysis, seems to have further indications of the major climatic cycles upon which the age of the Becerra has been estimated.

INTRODUCTION

IN describing the Becerra bone-bearing formation this paper intends to emphasize the importance of pedologic phenomena in its correlation throughout central Mexico (the southern portion of the Mexican Plateau) and to review the evidence† which has been used in its correlation with the standard glacial chronology of North America by Bryan (1946) and soon after by De Terra (1946, 1948).

DEVELOPMENT OF STRATIGRAPHIC CONCEPTS

The study of recent or sub-recent deposits in unglaciated areas has not been very intensive. This is also true in Mexico, where the great Mesozoic formations (and later the marine Cenozoic) received all the serious geological, particularly stratigraphical, attention.

Theodore Virlet d'Aoust (1857) may be considered the first modern-minded geologist who tried to explain the origin of the surface formations in Central Mexico. In recent times Fritz Jaeger (1926) applied more precise methods, but did not attain an adequate stratigraphic interpretation. Work on the biology of these beds by such distinguished scientists as Ehrenberg, Cope, Freudenberg, etc., did not contribute appreciably to defining the late sequences.

Interest in soils has been very keen in the past but from a purely agronomic point of view. Recently Nikiforoff (1943) pointed the way to the possibilities of pedological precepts in stratigraphic geology and Kirk Bryan and associates soon after published a series of papers (1943-1948) which seem to demonstrate the correctness of the principle.

Edward S. Deevey (1944) and Paul B. Sears (1948) have contributed modern pollen data which, particularly Sears', may be used to substantiate Bryan's climate sequence for the Mexico City Basin.

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*For discussion following the presentation of this and other papers, see p. 64.

†References at end of paper list only fairly recent or little known publications.

THE BECERRA FORMATION

It was first studied at Ciudad de los Deportes between the ancient towns of Tacubaya and Mixcoac, on the south-western edge of Mexico City, where it is over 16 m. thick. Ordoñez (1939) described the section before the more recent and voluminous excavations were made at these old brick pits, but did not apply any formational names. He remarked that the material had a loess-like character and, because of its vertebrate fauna, that it must be of Pleistocene age.

In 1944 the Mexican Geological Institute* undertook a survey of the Mexico City Basin in a more detailed manner, and the writer was assigned to the stratigraphy. At this time the great excavations for a novel sports development commenced and the cuts thus exposed, added to the already large brick pits, afforded unique opportunities for the examination of buried beds in an urbanized section to depths of about 20 m. and about 600 m. in an east-west direction.

Armenta horizon.—The stratigraphic sequence at Ciudad de los Deportes shows a prominent marker close to the middle of the bone-bearing bed, consisting of fine black sand and well-rounded andesite and pumice pebbles. It is about half a metre thick at the western edge of the excavations, but rather gradually becomes thicker and more organic, attaining at the easternmost end 2 m. of peat and heavy plastic clay with minor amounts of fine sand. This was called the Armenta horizon (Arellano, 1946), after the name of a farm formerly situated on these grounds, and it was believed to be the only really distinctive unit in the local sequence. Its riparian or marginal character was quite obvious, and we can now correlate it with some of the beach deposits proved by De Terra (1946, 1948) to have been formed in Becerra time. Its elevation, ca. 2,242 m., would indicate its correspondence with De Terra's El Risco beach, although other factors point to a little greater age,† in which case its preservation can be attributed to protection by the alluvial fan which was deposited on it in the later part of Becerra time.

Soil character.—The writer had the opportunity of presenting his field evidence to Prof. Kirk Bryan, who explained the beds at Ciudad de los Deportes, both above and below the Armenta horizon, as old soils now devoid of humus and recognizable only because their soil structure remained, as well as occasional remnants of minute roots. The relatively slow, but continuous, accumulation of medium fine clastic material in the alluvial fan area permitted the development of soil profiles and their subsequent burial. A number of granulometric analyses‡ showed the material to be poor in "fines." This could be interpreted as due to wind scouring and, indeed, the thesis originally expounded by Virlet§ on the importance of wind action in the Mexico City Basin hardly seems exaggerated.

The lacustrine facies.—The ancestral Becerra creek debouched into a lake‖ which measured about 40 km. east-west by some 60 km. north-south, flanked by two marked peninsulas, the sierras de Guadalupe and Santa Catarina and dotted with a number of volcanic islands.

Little of the clastics that were brought in by the stream actually reached very far eastward from the old Armenta farm. They were mostly deposited on the tip of the alluvial fan and, being exposed to wind action during the good part of the year, lost their fine fraction which was distributed throughout the basin and elsewhere, according to the direction and strength of the wind. Thus the sediments that accumulated in the central 10 or 20 km. of the lake were mostly wind-borne. Sedimentation being almost continuous and with a fairly dense organic population, especially at times of lower

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*Ing. Teodoro Flores, Acting Director of the Institute from 1941 to 1945, renewed with this and other projects (Paleozoic paleontology and stratigraphy of north-west Sonora by G. A. Cooper *et al.*) purposeful stratigraphy as a normal function of that organization.

†For radio-carbon dates of this beach-swamp deposit see page 61.

‡Executed for the most part by Srita. María de Jesús Contreras, formerly my assistant.

§*Op. cit.* p. 135–136, " Ainsi, on le voit, les courants aériens et les vents, dont on n'avait pas tenú compte jusqu'ici, ont joué un grand rôle dans les phénomènes géologiques et ont contribué peut-être autant que les pluies, que les lacs, que les rivières, a la formation de terrains epigéniques."

‖It has been proposed to call this lake, which may have been up to 30 metres or more in depth, Lago Bárcena, as a tribute to one of Mexico's most distinguished scientists and pioneers in the local geology.

levels, when the depth reached only a few metres, apparently prevented the development of any but rare laminations in the deposits.

The base of the Becerra lake beds is somewhat vague, but if it be taken where the limonitic character of the silts first becomes uniformly marked, the total thickness cannot exceed 5 m. and frequently is closer to 3 m.

A marked feature in the finest Becerra lake deposits is their bentonitic character; because of their fineness, their origin must be looked for in the volcanoes tens, or perhaps hundreds, of kilometres away. Major volcanism was evidently finished in the Mexico City Basin by Becerra time, but many volcanoes probably continued to emit varying amounts of clastic material and it is very likely that Popocatepetl, at the south-eastern tip of the Basin, may have contributed appreciably to the Becerra bentonitic lake deposits.

The alluvial facies.—The valley of Becerra creek becomes very narrow and box-like some 2 km. upstream (and west) from Ciudad de los Deportes. The Noche Buena brick pits here expose up to 5 m. of alluvium with much ceramic remains which overlie the Becerra formation along a weathered surface. The thickness of the exposed Becerra is of the order of 2 m., and its base can only be inferred from the outcropping Tacubaya (the next older formation and still considered Pleistocene) on the slopes. Several kilometres further upstream the relations between the underlying Tacubaya and the Becerra stream deposits (alluvium) may be seen extensively. Generally these are made of rather coarse sand and gravels with somewhat finer loams interspersed and may attain up to 8 m. in thickness, but mostly being under 5 m. In this creek the Becerra formation is only sparingly fossiliferous. The subdivision of the Becerra into two parts, suggested by the intercalation of the Armenta horizon at Ciudad de los Deportes, was observed by De Terra elsewhere and confirmed by Bryan. In the Becerra creek, however, it was not seen.

The aeolian facies.—At many places along the hilltops on both sides of Becerra creek (especially in its upper reaches, five or more kilometres west of Ciudad de los Deportes) there occurs a powdery grey deposit from a fraction of a metre to nearly 2 m. thick, lightly impregnated with carbonate of lime. The carbonate content and the finding of elephant bones in this bed prove its Becerra age. It constitutes a characteristic and widespread facies of the Becerra.

Contacts of the Becerra.—The underlying Tacubaya, compact, sandy, frequently with visible pumice and heavy lime processes (caliche) and with a characteristic pale brownish colour which varies from shades of orange to dark brown, serves to mark off the bottom of the Becerra; where it is lacking in this typical development the beginning of the Becerra may be a problem. The overlying formations are not differentiated as neatly as the Tacubaya, but they usually can be identified by their looser nature, lack of caliche, and ceramic content. A dark grey, or black " humic band " less than 1 m. thick, devoid of ceramic as far as known, occurs at Ciudad de los Deportes and elsewhere, and in those cases has been taken as the next younger formation, perhaps to be correlated with what De Terra (1946) has called Totolcingo. The bentonitic character of the mottled buff, greenish, or greyish silts intercalated with fine sand layers is what indicates with certainty the Becerra in the central Mexico City area, as distinguished from the overlying usually more uniform, dark muds of archeologic and later times.

OTHER IMPORTANT BECERRA LOCALITIES

For the sake of convenience the Becerra creek has been designated the type locality for the Becerra formation in five recognized facies, but its full description requires that at least a few of the more outstanding localities in and around the Mexico City Basin be reviewed. Furthermore a comparison of various localities will show the essential unity of the bone-bearing beds throughout the southern portion of the Mexican Plateau.

Tequixquiac.—This important Mexican Pleistocene vertebrate locality is some 60 km. north of Mexico City. It became famous in the last half of the past century because the large drainage excavations yielded an abundant and varied vertebrate fauna which, unfortunately, has been described only in part.

The following tabulation summarizes the chief stratigraphic features of a number of typical localities:—

1. The old travertine quarry whence Furlong (1925) has described *Capromeryx mexicana.*
2. Canal at the northern issue of the new drainage tunnel.
3. Arroyo Acatlán, 500 m. south of Tajo railroad station.
4. Old drainage canal at km. 47, just before entering the drainage tunnels (close to the town of Zumpango).

(1)

	0·2—0·5 m.	Black living soil.
Becerra (*travertine may be pre-Becerra*)	4—6 m.	Fine grey soft alluvium.
	6—10 m.	Cream to pink massive travertine. Upper contact very irregular. Fissures and caves filled with rather coarse sediments with fossil vertebrates.

(2)

	2·0 m.	Black soil.
Becerra	ca. 4 m.	Grey soil with some lime development (pedocal).
	0·1 m.	Fluvial gravel and sand.
	1·2 m.	Grey to yellowish hardened fossil soil.
	0·1 m.	Fluvial gravel and sand.
	3·0 m.	Light grey powdery soil with slight lime development.
	0·5 m.	Buff silt. Bottom of canal.

(3)

	2 m.	Black soil.
Becerra	2 m.	Hardened buff soil with much lime.
	2—3 m.	Grey hard soil with some lime and gravel lenses.
	1 m.	Greenish silt with nodules and veinlets of white kaolin-looking material.
		Bottom of creek.

(4)

	0·5 m.	Debris and living soil.
Becerra	1·3 m.	Light brown to grey fossil soil without appreciable lime in top 0·3 m.; grading into sandier material till bottom 0·15 m. is a fine soft grey sandstone.
	5·0 m.	Greenish silt with fine root holes turning sandier towards top where in uppermost 0·5 m. it shows some lime and well-rounded pebbles.
	0·5 m.	Buff-green fine sand.
	1·5 m.	Greenish silt with many fine root holes.
Tacubaya	10 m.	Hard yellowish brown fossil soil with nodules and veins of limonite. Uppermost 0·5 m. with thick lime development. Bottom of canal.

Nochistongo.—About 15 km. south-west of Tequixquiac. This locality is memorable because of a daring engineering accomplishment conceived and executed by the precursor of Lesseps, Enrico Martin (or Martinez). In one single dry season of some seven months duration he had dug many kilometres of canal and tunnel, so that man for the first time saw water issue from the land-locked Mexico City Basin. Many tons of fossil bone must have been removed during these incredible excavations, but the chronicles, as far as we know, do not mention these finds. Sparse mention in the literature and in museum labels is the only overt testimony of this fossil-vertebrate treasure.

One of the best examples of the erosional nature of the contact between the Becerra formation and the underlying Tacubaya is to be seen on the drainage canal opposite kilometre 49 of the Juárez railroad. The Tacubaya was incised by a trench about 4 m. deep which Lower (?) Becerra deposits filled, to be themselves overlain by 12 m. of aqueous-volcanic clastics of Upper (?) Becerra, which overlapped on to the Tacubaya. There is no appreciable angular discordance involved.

The thickness of about 15 m. attained here by the Becerra is unusual and nearly equals the development at Ciudad de los Deportes. The lithology of the upper part, 12 m. thick, is peculiar and does not conform closely to any of the five facies already described. It is a powdery grey-greenish, coarse silt with a distinct bentonitic aspect and with intercalations of volcanic sand, yellowish to snow

white, in beds up to 1 m. thick. Fossil bones of elephant, horse, ox, etc., are abundant but not too well preserved. The lower 3 m., a pale brown sandy silt, may be compared to the fine alluvium of Becerra creek, except for the lime development which is lacking in Nochistongo. The two parts of Becerra are separated by a lens of volcanic sand which reaches 1 m. in thickness. The base of the Becerra is marked by a coarse basal sand of 6 dm. which lies directly on a bed of Tacubaya pumice.

Valley of Toluca (*or Upper Lerma*).—Situated 50 km. west of Mexico City, it is over 300 m. higher, being separated by a ridge whose tops nearly reach 4,000 m. altitude. Elephant, horse and other fossil bones have been reported from numerous localities of which Almoloya de Juárez (12 km. north-west of Toluca) offers the best section. Just south of the village is an area deeply incised by creeks which expose much fossil bone material. These streams for the most part originate on the northern flank of a sub-recent volcano with a well-preserved cone, " El Molcajete," the lavas of which spread over a bed of pumice sand which may have originated in the last explosions of the Nevado de Toluca (25 km. south) and which in turn overlies the Becerra formation. The latter consists of 3 m. of typical fossil soil, whitish and rather hardened, in places almost a sand. Fossil bones are fairly common and on the same order of preservation as at Nochistongo. Underneath are 8 m. of Tacubaya, with some calcareous (caliche) nodules. It is noteworthy that the Becerra does not show any conspicuous lime development in the valley of Toluca.

Cope identified as *Teleoceras fossiger* a museum specimen labelled "Valley of Toluca" which may have come from this locality. This possibility and its implications will be discussed later.

Valle de Bravo.—This town is in the Balsas watershed, some 50 km. west of Toluca, at an elevation of ca. 1,800 m. Villada mentions it as a fossil bone locality. About 2 km. north-east of the town, in a gully, just below a small waterfall caused by a bench of southward dipping Cretaceous, or older, limestone is exposed a section of 4 to 6 m. of clastic material, the lower half of which contains fossil proboscidean, horse(?) and ox(?) bones, and fairly well-preserved wood. The material is dark grey, badly sorted, although mostly under sand size and contains numerous pebbles of the underlying supposedly Mesozoic formation. The degree of hardening and root structure, as distinguished from the top soil, may indicate a rough equivalent to the Becerra, but the lack of Tacubaya, or a recognized equivalent, and the vague paleontological evidence make a final decision impossible.

Tula, Hidalgo.—About 3 km. north-east of this well-known archeologic locality, where the main highway passes over the Requena irrigation canal, are 1 to 4 m. of a powdery white fossil soil resting on Tacubaya along a wavy contact.

The overlying formation contains ceramic and the separating surface is very irregular. We were unable to find fossil bones, but the character leaves little doubt as to the correlation with Becerra.

Chicabasco, Hidalgo.—About 100 km. north-north-east of Mexico City and about 10 km. south of Actopan. This locality is reputed to have been visited by Humboldt. The creek which runs north past the western edge of the old hacienda buildings exposes along its banks a rather hard, tufaceous, bone-bearing formation several metres thick which may be Becerra.

Regla.—On the eastern and rainy side of the Sierra de Pachuca, some 25 km. north-east of Pachuca, is an area from which elephant fossils have been reported. North-east of the San Miguel Regla hacienda house a broad hill is capped by lime-stained basalt, and on one side of it several metres of a pedalferized soil contain cobbles of the basalt, thus proving that the latter is the older. The fossil soil may be Becerra because, besides being lime-stained, it is underlain by another fossil soil of the same general nature but which, instead of basalt, has pumice and obsidian inclusions and is also lime-coated, conforming to the Tacubaya.

Tepexpan.—About 30 km. north-east of Mexico City, this locality has yielded some of the best specimens of what has been referred to *Mammuthus* (*Archidiskodon*) *imperator* (Leidy) (Arellano, 1946a). It has also produced the best Pleistocene human skeleton in America. Texcoco lake stil

covers parts of this zone at high water, and no sizeable streams enter from that area, so that, contrary to what has been described at Ciudad de los Deportes, we here have more or less normal lake deposits within several hundred metres from shore. At the site of the human find the stratigraphy is similar to that of the surrounding area for several kilometres. The living soil is uniformly shallow, usually not much more than 2 dm. and supports a specialized thorny grass (zacahuixtle) which thrives on the salted water of Texcoco lake. Under this veneer may be found a layer of soil heavily incrusted with lime and underneath, more or less sharply set off, a buff silt full of fine roots, diatoms, and gastropods; the buff colour generally becomes greenish or greyish in the lower part of the 2·5 to 3 m. which we assign to the Becerra. The elephant remains have invariably been found in this layer. Where the silt assumes a distinct brown colour we feel should be the top of the Tacubaya.

Apatlaco.—In the Ixtacalco section of Mexico City, about 6 km. east of Ciudad de los Deportes, what appears to have been a complete elephant skeleton was found at from 1 to 2·5 m. depth. This locality is of special interest because it represents conditions rather far from the slopes of the basin. It is in the chinampa district (so called " floating gardens," a myth which has persisted even among educated people to this day) where the farmers dug canals around a plot sometimes less than 40 m. on a side and spread the earth on their land. This lowered the water table enough to enable them to till the soil, retaining the moisture close to the roots of the plants. Since the effective artificial drainage of the Mexico City Basin from 1900 on, this farming method was doomed, and in this particular area the ground water level is now 3 to 4 m. deep.

The upper metre is a dark grey loose earth which seems to have been subject to the effects of cultivation and contains ceramic. Underneath follows the elephant-bearing layer which consists of: another metre of a somewhat more compacted fossil soil, the lower 3 dm. being very sandy; a 2 cm. layer of white diatomaceous earth; 7 dm. of olive-coloured silt with soil structure and much fine plant material in good preservation, interrupted by several layers of fine sand 2 to 5 cm. thick. Immediately below is a 2 dm. horizon of fine sand which suggests a beach, and at that level it would be among the lowest Becerra beaches recorded thus far. The sand rests on 2 dm. of an olive silt as above, which seems to mark the lowermost Becerra, since below the limonitic colouration considered Tacubaya becomes persistent.

Tamazulapan, Oajaca.—The Mexican Plateau has a narrow southern extension which projects to central Oajaca. Along this extension, some 300 km. by air south-east of Mexico City, is the valley of Tamazulapan, State of Oajaca, wherein is developed a bone-bearing formation which may be correlated with Becerra. The known bone localities are on the north-east side of the village of Tamazulapan in a whitish, pulverulent, sometimes very sandy material, four or more metres thick, which contains travertine with good plant impressions. The local sequence has been investigated because of a human skeleton found by Professors Carl O. Sáuer and Sherburne F. Cook (MS.), in a stratigraphic situation suggestive of considerable age.

AREAL EXTENT OF THE BECERRA

As outlined by the foregoing localities, the Becerra formation may be considered recognizable from central Oajaca to central Hidalgo, some 400 to 500 km. in a north-west—south-east direction. Its best development is apparently in the Mexico City Basin and immediate vicinity, but it is found in all the large depressions of the Mexican Plateau above 1,800 m., where climatic conditions seem to have undergone major oscillations of the same order of magnitude. Northwardly the Becerra may be expected to the limits of the state of Guanajuato, but beyond it does not exist in any closely comparable form. Two explanations suggest themselves; one is that the later, dry phases may have been too uniform for the diagnostic pedologic phenomena to develop; the other is that aeolian-volcanic sediments, which give the Becerra much of its characteristic lithology, may have been less abundant, or lacking, in the northern latitudes.

AGE AND TELECORRELATION OF THE BECERRA

A major obstacle to a final decision on the age of the Becerra is the lack of paleontological or other conclusive evidence as to the age of the Tacubaya, the underlying formation, in which no fossils of any kind have been recognized. Recent published work by Arellano and E. Azcón (1949) indicates that the Tacubaya is probably early Pleistocene. J. R. Arnold and W. F. Libby have circulated radiocarbon dates, in September, 1950, giving 11,000 and 16,000 (at least) years as the age of peat and wood, respectively, from the Armenta Horizon at Ciudad de los Deportes. The Becerra, as here described, must therefore be considered a more complex stratigraphic unit, perhaps including Illinoian (Third Glacial, or Riss) time.

Bryan (1946, 1948) considers the Becerra as Wisconsin-3 (Mankato-Cochrane) and would correlate the Tacubaya with Wisconsin-2 (Tazewell-Cary). His criterion is largely based on pedologic phenomena as observed throughout the Mexican Plateau (including its natural extension into the United States). This stratigraphic method is new, but where properly applied seems to be consistent and capable of trustworthy results.

De Terra (1948) prefers to correlate the Mexican Pleistocene with the pluvials of Antevs and the California glaciation of Blackwelder, and on that basis equates the Becerra to the Provo Pluvial and Tioga Glacial, while the Tacubaya he would consider Bonneville Pluvial, or Tahoe Glacial. His methods are lake level and glacier studies in relation to anthropic problems.

In either case, if the age of the underlying Tacubaya could be considered with certainty as Wisconsin, the age of the Becerra would be fixed within fairly narrow limits. However, this must remain problematical till representatives of the earlier glacial stages are recognized.

Paleontological evidence would indicate, if taken from the published literature, that what we are calling the Becerra formation must be of considerably longer range than the span of the Wisconsin, but unfortunately most of the material which has served for these identifications was either old museum specimens, or pieces which had changed many hands from the original collector to the vertebrate paleontologist and thus the provenance cannot be too well established.

A recent study by Prof. Chester Stock on material collected by Prof. Francisco Contreras, of the Geological Institute of Mexico, in 1937-1938, from Tequixquiac, has apparently not yielded any of the species that might indicate an age older than Pleistocene.*

It is interesting to note that mastodon teeth have not been authenticated from the beds we call Becerra, although they have been reported (doubtfully, we say) as from Tequixquiac and elsewhere by Freudenberg and others.

The upper age limit of the Becerra may be ascertained somewhat better than the lower one. Bryan's original contention that the Becerra terminated with the fairly prolonged dry spell of from 5500-2500 B.C. has not been seriously challenged. Any error contained in this estimate certainly must be on the side of too recent, since the 2500 B.C. minimum age seems too short to allow for the development of the lithic Chalco and ceramic cultures. Antevs' figure for the termination of Provo Pluvial of 7000 B.C. will probably be more satisfactory for the end of the Becerra.

The dry period following the Becerra has been named by Bryan (1948) Barrilaco. It produced a distinctive lime development which has served, among other places, at the Tepexpan Man site, as a seal which effectively demonstrates that whatever may be underneath is of Becerra or older age. Elephant bones have never been found above this horizon.

In connection with the problem of the disappearance of the mammoth we may thus say that, in the southern Mexican Plateau, it happened between 7000 and 4500 B.C. (using Bryan's span of 2,500 years for the last dry period and Antevs' figure for its beginning). The intervention of man must have been the decisive factor in this extermination, as obviously the aridity was negligible over certain areas where otherwise the large fauna might have taken refuge.

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*Personal communication. August 2nd, 1945.

Further evidence of certain major climatic cycles, from the present back to the Pleistocene, may be adduced through the pollen profiles elaborated by E. S. Deevey (1944) and P. B. Sears (MS.).

The pollen results of Deevey refer to Lake Patzcuaro—one of those protected areas where the dry spells have not been felt in all their rigour, at least as far as pedologic testimony can certify, for no appreciable lime development occurs. The pollen diagram is quite uniform, but Deevey is inclined to interpret the upper metre or two of lake sediments as indicating a slightly wetter period than the preceding, which is represented by a metre or so of sediment which might be slightly drier than the initial wetter period extending to the bottom of the six metres sampled.

In the Mexico City Basin where Sears worked in the spring of this year (1948) more marked contrast should be expected, and the preliminary interpretation indicates that such is the case but, unfortunately, final decisions are still pending and we cannot make use of Prof. Sears' generous offer to allow the use of his results in this paper.

More or less close equivalents of the Becerra are suggested by at least two formations which have been described within recent years, the Neville (Albritton and Bryan, 1939) and the Tarija beds, horizon B, of Bolivia (Oppenheim, 1943). The latter is particularly suggestive because latitude, altitude, and climatic environment seem to be identical to those under which the typical Becerra is found. The thickness of some 20 m. given for the Tarija horizon B, bone-bearing beds is in excess of what has been observed for the Becerra. This fact and the existence of two ferruginous layers near the top might mean a greater range than at present is conceded to the Becerra.

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LOWER LIMIT OF THE PLEISTOCENE IN AFRICA*

By L. S. B. LEAKEY

Kenya

ABSTRACT

With the great increase of research all over the African Continent on the problems of the Stone Age in relation to geology and to fossil fauna, the need to have a clear definition of the Plio-Pleistocene boundary becomes urgent. Workers in different parts of the Continent are using different criteria, resulting in considerable confusion. A clear definition is also needed in order to make correlation between Africa and different parts of the world feasible. In Africa the problem is complicated by the fact that many mammalian genera normally regarded as typical of the Pliocene survived well into the Pleistocene.

The first Pan-African Congress on Prehistory, in January, 1947, resolved, on the advice of its Geological Committee, to use the terms Kageran, Kamasian and Gamblian to represent the Lower, Middle and Upper divisions of the Pleistocene, with the beginning of the Kageran period representing the Plio-Pleistocene boundary.

It is suggested that the Kamasian should be divided, and the Upper Kamasian given a distinctive name; the reasons for this suggested division are both geological and faunal.

The mammalian fauna of the Kageran in East Africa seems to correspond broadly with that of the Villafranchian in North Africa and Europe. It includes many genera which might normally be regarded as Pliocene, but also contains more evolved genera, including true elephants. It is therefore suggested that the Villafranchian of Europe and North Africa be regarded as the equivalent of the Kageran in East, Central and South Africa: and that the Villafranchian be regarded as the first stage of the Pleistocene, with the Plio-Pleistocene boundary immediately anterior to it.

ON THE IMPORTANCE OF THE ELEPHANTS IN THE PLIOCENE-PLEISTOCENE BOUNDARY AND THE STRATIGRAPHY OF THE PLEISTOCENE IN EUROPE†

By MADELEINE FRIANT

France

RÉSUMÉ

J'estime, comme un certain nombre d'auteurs (dont E. Haug), que le Pléistocène commence avec le Villafranchien, c'est à dire avec le début de l'extension des glaciers alpins.

Au point de vue de la faune terrestre, le Pléistocène ainsi conçu se caractérise par l'apparition de trois genres mammaliens émigrés de l'Asie: le genre *Elephas*, le genre *Equus* et le genre *Bos*.

En ce qui concerne le genre *Elephas*, les quatre espèces fossiles d'Europe: *E. planifrons* Falc. et Cautl., *E. meridionalis* Nesti, *E. antiquus* Falc., *E. primigenius* Blum., constituent des critères stratigraphiques importants pour le Pléistocène de nos régions.

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*This paper is printed in full in Part IX of the Report. For general discussion following the presentation of this and other papers, see p. 64.

†For discussion following the presentation of this and other papers, see p. 64.

Discussion following the presentation of the eight preceding papers

(*Note.*—These papers were presented at the Joint Meetings of Section H, The Pliocene-Pleistocene Boundary, and Section K, The Correlation of Continental Vertebrate-bearing Rocks. For other relevant discussion see Part IX of the Report which contains the proceedings of Section H.)

T. M. STOUT and R. C. MOORE drew attention to the valuable zonal work which had recently been done, and was still going on, in Nebraska.

W. B. METRE said he had been much interested in Dr. Wadia's paper on the transitional passage of Pliocene into the Pleistocene in the north-western Sub-Himalayan Region and his suggestion that the Boulder Conglomerates of this area (Upper Siwaliks) were of Lower Pleistocene age. Similar beds, known as Dihing pebble beds, occurred in the Dihing series of Assam (N.E. India). These beds were probably about 10,000 feet thick. They had been affected by the immense tectonic movements which involved vertical and horizontal displacements of several miles. Was it possible that such deposition and severe tectonic movements had all taken place in Pleistocene times? Might it be worth while investigating whether the deposition of the Boulder Conglomerates and pebble beds started in the late Pliocene period?

D. N. WADIA said it was not possible to divide a 10,000-foot thick conglomerate in the Upper Tertiaries of Assam, in the absence of any definite fossil evidence, and to assign the folding movements experienced by the conglomerates to a definite horizon in the Pleistocene. In the western Sub-Himalayas Lower Pleistocene beds had undergone considerable tectonic movement, some beds even showed lateral thrust. Fossils alone could date the movements seen in Assam.

C. A. FLEMING said that as a New Zealand geologist he welcomed what amounted to a climatic definition for the base of the Pleistocene for it gave hope for the correlation of areas lacking mammalian and human cultural evidence. Quantitative bio-statistical methods of deducing the temperature facies of Plio-Pleistocene marine faunas (as initiated by Prof. H. G. Schenck in California) might be recommended to assist fixation of this climatic base in isolated regions.

HUBERT G. SCHENCK replied that with regard to the use of biometrical methods of analysing molluscan faunas in the effort to define the Pliocene-Pleistocene boundary in California, the war had prevented him determining if the inferences had been tested. The question gave him an opportunity to remark further that it was instructive that the Commission had defined the Pliocene-Pleistocene boundary without specifying what kind of a boundary—of an epoch, stage, age, system, series, or what? Moreover, it had been interesting to listen to the discussion that day because about twenty years ago in California they had begun to consider the problem. There, the marine Pliocene and Pleistocene strata totalled some 14,000 feet in thickness. Because of the presence of petroleum, these rocks and their fossils had been studied intensively without leading to universally-accepted criteria for defining the base of the Pleistocene series. Finally, in Japan, Dr. Hatai had been studying this boundary problem for two years; his work was not yet completed.

EDWIN H. COLBERT said that the Upper Siwalik sediments, divided from bottom to top into the Tatrot, Pinjor, and Boulder Conglomerate formations, had been variously correlated by several authorities during the past few decades. According to the older view, as advocated especially by Pilgrim, the Tatrot and Pinjor horizons might be placed in the Upper Pliocene period, while the Boulder Conglomerate formation was accorded a Lower Pleistocene age.

It was his contention, and in this he followed the suggestion first made by Matthew, that the Pinjor formation was truly of Villafranchian age. Here were found true *Equus*, camel, early mammoth, *Leptobos* and other advanced mammalian types. There were, in addition, certain " primitive " genera in the Pinjor and these greatly influenced Pilgrim in his views on Siwalik correlation. However, these were regarded as persistent forms, and of much less importance in evaluating the age of the Pinjor than were the progressive mammals of Villafranchian affinities.

Since some of these Villafranchian forms appeared in the Tatrot, as well as in the Pinjor, it seemed advisable to regard the Tatrot also of Villafranchian age.

Thus, if the Plio-Pleistocene boundary were to be drawn at the base of the Villafranchian, the whole of the Upper Siwaliks sediments would fall within the Pleistocene.

IMPORTANCE DES FAUNES DE MAMMIFÈRES DANS L'ÉTUDE STRATIGRAPHIQUE DE L'EOCÈNE, DE L'OLIGOCÈNE ET DU MIOCÈNE

Par MARGUERITE RICHARD

Algeria

RÉSUMÉ

L'établissement de la chronologie des terrains tertiaires continentaux se révèle pleine de difficultés, les invertébrés terrestres constituant en général de mauvais " fossiles d'étage," les passages latéraux avec les formations marines étant difficiles à observer et, de toutes façons, ne pouvant intéresser qu'une zone très restreinte.

De plus, à mesure que l'on avance dans le temps, les bassins marins se réduisent, se fragmentent et s'isolent, les faunes marines du Tertiaire sont donc elles-mêmes souvent variables suivant les points considérés.

Les mammifères, qui ont été remarquablement étudiés au point de vue paléontologique et phylogénique, l'ont été beaucoup moins au point de vue stratigraphique, et peu d'auteurs leur accordent un crédit quelconque à ce sujet. Il semble cependant que l'on puisse grâce à eux établir une chronologie assez précise des formations continentales, une espèce, ou une association de deux espèces étant souvent caractéristique au moins d'un étage, sinon d'un sous-étage.

De plus, la fixation des " grandes coupures " du Tertiaire, en particulier les limites entre Eocène et Oligocène et entre Oligocène-Miocène, qui a donné lieu à d'innombrables discussions pourrait, si les auteurs y souscrivaient, être basée sur l'observation des faunes de mammifères.

DISCUSSION

HUBERT G. SCHENK enquired how Mlle. Richard correlated the type Aquitanian with the Chattian.

MARGUERITE RICHARD replied: La question est posée de savoir pourquoi je n'ai pas parlé de l'étage Chattien.

Le Chattien a été établi dans le bassin de Mayence, où l'on de sait encore pas exactement s'il doit être rattaché au Stampien supérieur où à l'Aquitanien inférieur. On a ensuite voulu le définir dans les autres bassins tertiaires, où, suivant les cas, on a choisi le sommet du Stampien ou la base de l'Aquitanien pour en faire le Chattien. Il en est résulté de graves confusions, accentués encore par le fait qu'on a voulu lui donner un fossile caractéristique, *Helix ramondi*, qui en réalité, s'étend du Stampien inférieur à l'Aquitanien peut-être supérieur. Le terme de Chattien me paraît donc devoir être supprimé de la littérateur géologique, au moins en temps que nom d'étage.

E. H. COLBERT pointed out that in the U.S.A. a Committee had been formed to draw up stage names of the American sequence. European practice so far had not been as accurate as could be desired, and the Geological Society of America had published the opinion of the Committee. The immediate problem was how to tie in the United States and French names.

T. M. STOUT drew attention to the Great Plains marine succession. The series from the base of the Oligocene to the Pleistocene and recent was now known, and some correlation was now possible on the basis of fossil mammals.

D. M. S. WATSON said that much would yet come from the U.S.S.R. There lay the migratory route; India and Africa were mere dependencies.

MAIN VERTEBRATE HORIZONS IN CHINA, THEIR GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION, FAUNISTIC CHARACTER AND CORRELATION

By C. C. YOUNG

China

ABSTRACT

Six main series of vertebrate remains in China are briefly described—Devonian fishes, Triassic theromorphs and saurischians, Jura-Cretaceous dinosaurs, early Tertiary mammals, Mio-Pliocene mammals, and Plio-Pleistocene vertebrates. Localities of Mesozoic mammals and Pleistocene man are also reported. The geological and geographical distribution and the leading characters and affinities of each main group to the forms of other countries have been discussed briefly. With the help of a locality map of the main fossiliferous sites in China, and a chart showing the stratigraphical and general features of those faunas, the main vertebrate fossils in eastern Asia are summarized.

The Devonian fishes so far known are restricted to South China. The Lower Triassic fauna is restricted to North China, while the Upper Triassic one is only known in the Yunnan Province. The sites of Jura-Cretaceous dinosaurs are mainly located in North China. The same is true for the early Tertiary and Mio-Pliocene fossils. The cave and fissure deposits, with vertebrate remains at least, are widely distributed in South China, in addition to the famous fissure deposits at Choukoutien with fossil man, and the rich fossils from the lacustrine and slope facies from North China.

Each series can be roughly correlated with that of another country. The barren levels, so far known, have either little promise of fossils on account of unfavourable preservation or are apparently barren, due to the coarseness of the deposits. The crustal movements in various geological times appear to be connected with the absence of fossils of the particular period on the one hand and with the subsequent rich remains on the other.

INTRODUCTION

TEN years have elapsed since my *Review of the New Vertebrate Horizons in China* was published. In this paper, progress in the development of vertebrate palaeontology in China is briefly discussed. During the ten hard years of war, only a few localities and horizons were added to what we had achieved up to 1937. Yet at least two important horizons were discovered as well as some minor new localities of already known levels for vertebrate remains. One locality has the Devonian fish beds with *Cephalaspis*, *Bothriolepis* and *Parexus*-like acanthodians found in Yunnan, Hunan, Kwantung, and Kwangsi provinces, indicating for the first time that rich deposits of Palaeozoic vertebrates are found in China. The other has the rich saurischian-bearing beds in Lufeng, Yunnan, with the *Tritylodon*-like form, *Bienotherium*. Up to now we have not traced any similar fauna in other parts of China, but the fauna of Lufeng is so rich and significant that we have to consider it as one of the most important horizons. I have given a historical review of the development of vertebrate palaeontology in China in my previous paper, but I give supplementary notes here, and all the important localities bearing vertebrate remains are plotted in the accompanying map. Using this I shall try to summarize what we know and what we expect to know of the vertebrate palaeontology of China.

I. SIX MAIN GROUPS OF VERTEBRATE REMAINS

Except for Tibet and adjacent regions which are still a palaeontological blank, all the other parts of China have yielded vertebrate fossils. During the last thirty years of exploration by Chinese geologists in various parts of China, our knowledge of vertebrate palaeontology has been considerably increased, as it also has been by the efforts of some famous expeditions, notably the Central Asiatic Expedition of the American Museum of Natural History, and the Sino-Swedish Expedition. It is quite possible

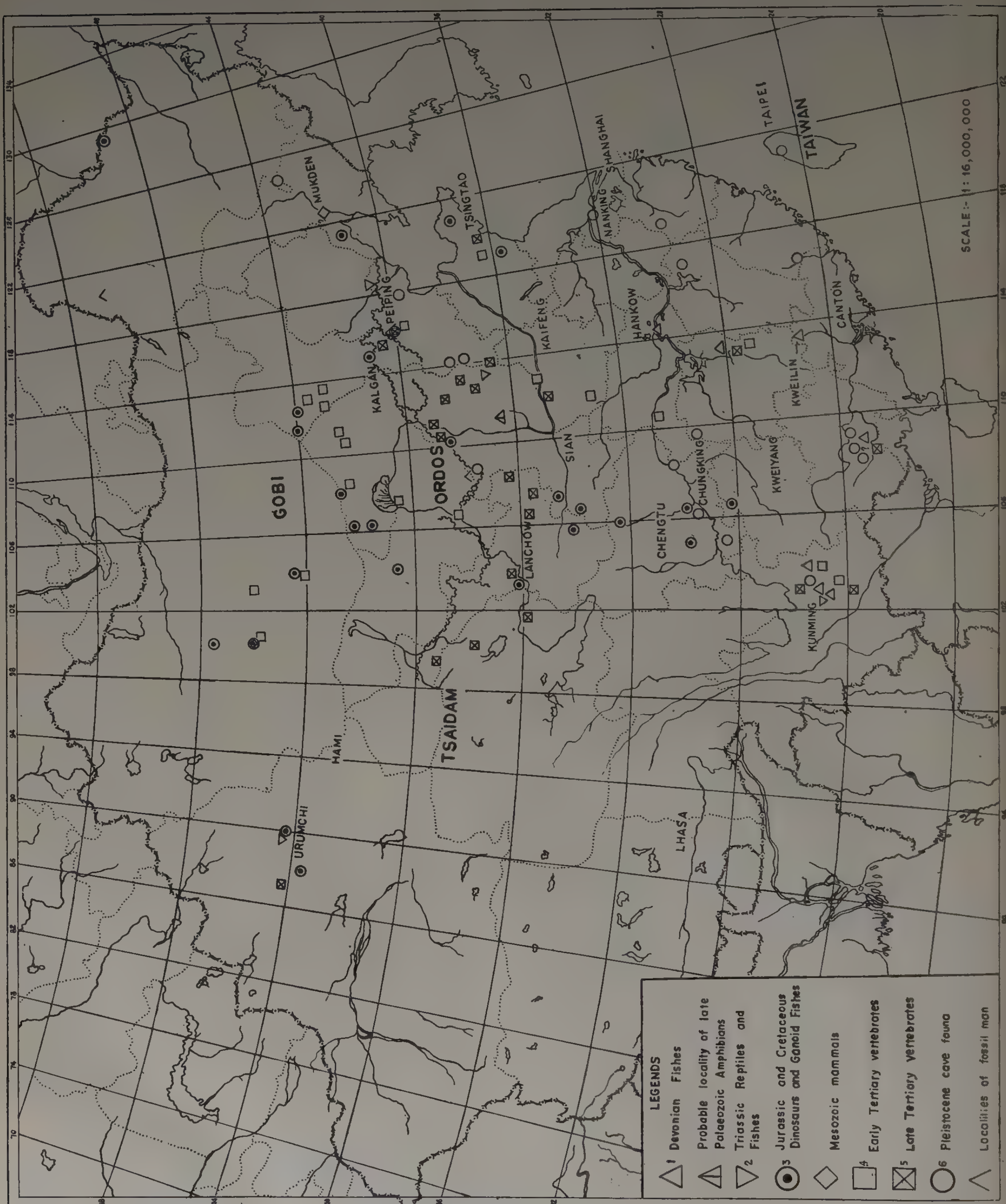
that some important horizons may have escaped the eyes of palaeontologists and geologists. Notwithstanding the comparative scarcity of the fossil localities, we have to admit that the main horizons known represent the principal fossil-bearing levels, while those periods without vertebrate record are those that are comparatively poor in such remains. On this assumption we may summarize the six important faunistic groups of vertebrates in the huge sequences of sedimentary rocks so widely distributed in China.

1. *The Devonian fish beds.*—Although remains determinable as *Bothriolepis* have been found by Chi from Tiaomachian, Central Hunan, *Cephalaspis* has long been known from East Yunnan. Unfortunately, the latter is not yet satisfactorily described. During the war *Bothriolepis* and similar forms were reported to be common in Kungyang and Fuming in Yunnan, North Kwangtung, North Kwangsi and Central Hupeh and proved to be from the widely distributed level in the Devonian rocks of China; additional finds of cephalaspids were also secured from East Yunnan. Some Chinese geologists regard the beds with *Bothriolepis* as somewhat older than Upper Devonian as it is usually regarded in Europe and North America, but it seems useless to argue before the finds of various localities have been properly described. Anyway, it is certain that in the Devonian of China where the " Old Red " facies is developed fish horizons may be expected. This assumption is reinforced by the newly recorded acanthodii-remains from the Lower Devonian of Yunnan. It would be of great importance to trace those beds in order to throw some new light both on stratigraphy and on palaeontology.

2. *The Triassic Theromorph and Saurischian beds.*—The Triassic of China is one of the most important vertebrate-bearing formations. Two main horizons may be noted. The lower one, with *Lystrosaurus*, *Chasmatosaurus*, *Santaisaurus*, etc., is remarkably similar to the *Lystrosaurus*-zone of South Africa, both in its contents and in its lithology. It is possible that the lower limit of the fossiliferous beds may extend to the Upper Permian, as is indicated by the presence of the genus *Dicynodon*, but it cannot yet be proved stratigraphically. The upper beds are characteristically known as the Lufeng Series with very rich saurischian remains and *Bienotherium*. So far as we know this fauna is only recorded at Lufeng and its vicinity. This fauna is also closely comparable with the similar beds of South Africa. In South-East Shansi the upper part of the Middle Triassic fauna is also reported, including a *Kannemeyeria*-like form, but this is still less adequately known. The continental facies of the entire Triassic fauna is widely and extensively developed in many parts of China, especially the North-Western regions, so that it is very likely that what we know now is but the beginning of knowledge of the vertebrate life in that period.

3. *The Jura-Cretaceous Ganoids and Dinosaurian fauna.*—The next important horizon is represented by the rich Jura-Cretaceous vertebrate faunas, characterized by an abundance of ganoids and dinosaurian remains. The former cannot yet be fully studied but are largely represented by forms close to such genera as *Sinamia*, *Pholidophorus*, *Lepidotus* and others. These fishes, together with many widely separated localities of dinosaurs such as *Tienshanosaurus*, *Omeisaurus*, *Helopus*, *Sanpasaurus*, etc., seem sufficient to indicate an Upper Jurassic rather than Lower Cretaceous age. This vertebrate-bearing formation, certainly in the Szechuan basin and probably also in other places, is very similar to the Purbeckian-Wealden of the European sequence and to the Morrison Formation of the American classification. On the other hand, the dinosaurian beds north of the Great Wall are exclusively of Lower to Upper Cretaceous age. So far as we know, there is no satisfactory means of correlating them although some writers prefer to assess the age of *Helopus* and *Tienshanosaurus* as Lower Cretaceous. Generally speaking, it seems that the southern dinosaurian beds are largely characterized by an abundance of sauropoda, the northern facies by ornithischians. With the exception of Laiyang in East Shantung with *Tanius*, an ornithischian, we do not know any undoubtedly Cretaceous dinosaur south of the Great Wall. In any case Jura-Cretaceous time in China is marked by another group of vertebrates which extends certainly to Mongolia and probably to Indo-China as well.

4. *The Early Tertiary radiation of mammalian remains.*—The main fossiliferous horizon of vertebrate remains in Palaeogene time is restricted to the Eo-Oligocene period, and is widely distributed in Outer Mongolia and North and South China, while the Palaeocene is only known in Gashato,


MUKDEN
TSINGTAO
SHANGHAI
NANKING
TAIPEI
TAIWAN
PEIPING
KALGAN
KAIFENG
HANKOW
CANTON
KWEILIN
SIAN
ORDOS
GOBI
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CHENGTU
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TSAIDAM
HAMI
URUMCHI
LHASA
SCALE :- 1: 16,000,000
LEGENDS
1 Devonian Fishes
Probable locality of late Palaeozoic Amphibians
2 Triassic Reptiles and Fishes
3 Jurassic and Cretaceous Dinosaurs and Ganoid Fishes
Mesozoic mammals
4 Early Tertiary vertebrates
5 Late Tertiary vertebrates
6 Pleistocene cave fauna
Localities of fossil man

FIG. 1

Outer Mongolia. In contrast to the lake facies and the undisturbed condition of the Early Tertiary basins of the Gobi region, the sediments of the same age in other parts of China are of much coarser nature, mostly Piedmont in origin, since these other parts were affected by mountain-making movements. Consequently the latter afford usually some fragmentary specimens. Most of the widely distributed Early Tertiary beds south of the Great Wall have so far proved barren, with little hope of yielding a rich fauna. The precise geological age of these beds is therefore in many cases only a tentative one. The general character of the fauna is, however, closely comparable with those found in the North Chinese provinces, Suiyuan, Charhar, etc. That is to say, the same Eo-Oligocene age with even the same species.

5. *The Mio-Pliocene fossiliferous beds.*—Formerly, even the Upper Miocene was a blank space in the palaeontological record of China. This gap was, however, recently filled by the discovery of the Tunggur formation in Suiyuan and the Shanwang Series in Shantung. Both contain the same fauna of decidedly Upper Miocene age. There are new indications that similar beds may be found in Central Kansu and the eastern slope of Taihangshan.

The most important horizon of this series is represented by the rich lower Pliocene bone-beds known as the *Hipparion*-fauna of Pontian age. The typical regions of this fauna are North-West Shansi, South-East Shansi, West Honan, North-East Shensi, and East Kansu within the rectangle of Taihangshan-Yinshan-Liupanshan-Tsinling of Teilhard. New field researches prove, however, that this fauna is extensively developed westwardly in the Kansu and Chinghai region up to the border of the Tsaidam basin. Traces of this fauna are few in South-West China and entirely absent, so far, in South-East China.

Definite Middle Pliocene beds are known in the Ertemte fauna in Suiyuan, the Chinglo Series and the middle zone of the Yueshe Formation in Shansi. They are, however, rather poorly represented.

6. *The Plio-Pleistocene lake and cave fauna.*—The last group of the vertebrate radiation in China is in Plio-Pleistocene time and was formerly known as the Sanmenian. The lower one, uppermost Pliocene in age, is dominantly lake facies and is typically represented by the Nihowan fauna. This fauna has a wide extension. The Lower Pleistocene is characteristically represented by cave deposits. They are also widely distributed in China with, however, some minor differences in age. The loessic fauna is also richly represented by the Sjara-osso-gol deposits of lake or rather fluvial nature. In the genuine loess, however, vertebrates are rather poorly known, so that the loessic fauna is not nearly so well recorded as that of the preceding time.

In the accompanying map three things are additionally reported. First, the probable presence of an amphibian in South-West Shansi, presumably from the Permian limestone, which shows how poor the vertebrate record is in the late Palaeozoic. Second, localities with Mesozoic mammals (*Bienotherium* excluded) are located. These are in connection with the third, Jura-Cretaceous group. Third, localities with fossil man are recorded or suggested, belonging mostly to the cave or fissure deposits.

II. GEOGRAPHICAL DISTRIBUTION

A glance at the map of the six main fossiliferous horizons in China shows that most of the fossil-bearing localities are concentrated in North China and Mongolia and only sparsely represented in South China. They are still less known in the north-eastern nine provinces (Manchuria) and Sinkiang, and almost unknown in Eastern Outer Mongolia and Tibet and its adjacent regions. With the exception of the last area, which is practically unexplored, the paucity of remains in other parts of the country cannot be explained simply by the lack of field survey, as the geology of South China, for instance, is just as well known as that of the North. We may therefore assume that this map is an indicator as to where fossils may be found and what kind of vertebrates may be expected in any particular region. The following lines may be added as supplementary notes to the distribution of each main faunistic group discussed above.

1. The Devonian fish beds seem restricted to South China, and south of the Yangtze River. The Devonian rocks are entirely absent in North-East China and in South-West China. They are developed

as marine facies in most cases. Where the red sandstones occur it is very likely one may find more fish localities. In Kwangsi and its bordering region, the lower Palaeozoic rocks are continentally developed in the Lungshan Series, so we may expect to find some fish beds even older than the Devonian.

2. Unlike the fish beds, the Lower Triassic horizon is restricted to the north. The main locality lies on the northern foot of Tienshan. Despite the remarkable similarities between the beds of China and those of South Africa we have no site of the same age reported from any other part of China. The same is true for the upper Middle Triassic locality in Shansi. The Upper Triassic beds are only known in Yunnan. A glance at the geological map of China reveals that the Triassic rocks are widely developed as continental facies, so that we have every hope of finding more horizons and localities with Triassic vertebrates.

3. The Jura-Cretaceous beds with dinosaurian remains and ganoid fishes are recorded in Outer Mongolia and North China as well as in Sinkiang and prove to be the most widely distributed vertebrate horizon. Recently these fossils have been found in the Szechuan red basin. So far, the only locality with sauropoda recorded is in North Keichow south of the Yangtze River. In South-East China Jurassic and Cretaceous beds are also extensively developed in continental facies. Why no similar finds have been reported remains a question.

4. Although the Early Tertiary rocks are widely known throughout the whole of China, the rich beds and localities with vertebrates are especially well represented in the regions of Outer Mongolia, Charhar and Suiyuan provinces. In the regions of the Yellow River and the Yangtze River, only a few localities have been reported, and nothing is known south of the Nanling Range in the Chukiang Region. The reason is obvious since, in most parts of China, the sediments of this age are much too coarse for the preservation of remains and have also suffered from subsequent movements.

5. The typical Pontian fauna is mainly restricted to North China as already stated above. It seems certain that in the border regions of the Tasdam basin and also in the mountain lands of Nanshan and Kunlun the Pliocene basins with the Pontian fauna are frequently developed. In the Hopei plain, along the eastern slope of Taihangshan the fauna of the same age may be met in fissure or cave deposits. Lacustrine facies of the same age have not so far been reported north of the Yangtze, but are rather well known in South China with fragmentarily preserved vertebrates.

6. The Plio-Pleistocene fauna is well known in China. Most of the fissure deposits are limited to the south-east of the line between Peiping and Kunming; that is to say, restricted to South-East China. The loamy facies extends further west but is almost unknown south of the Tsingling Range.

III. MAIN CHARACTERS OF THE FOSSILS

With few exceptions most of the above vertebrate localities have not been systematically explored and collected. The better-known localities where thorough work has been done are the Upper Triassic Lufeng fauna, several localities of Early Tertiary beds in Charhar and Suiyuan, the *Hipparion* fauna in North-West Shansi, South-East Shansi, North-East Shensi, West Honan, and the Plio-Pleistocene fauna of Nihowan and Choukoutien. It is, therefore, obvious that besides these few cases the real composition of the fauna of most of these localities is not truly representative and many interesting fossils are likely to be missing. In other words, it is still too soon to get a real picture of the vertebrate life based on present data, and further extensive research is necessary. With this fact in mind, I may summarize what we know now about the leading characteristics of those vertebrate-bearing beds.

1. Needless to say, the Devonian fish beds, although poorly known, are characteristically represented by *Cephalaspis* and *Bothriolepis*. By more extensive research many archaic fishes should come to light.

2. As for the Triassic vertebrates, all the three main levels with those index forms sufficient to show the remarkable features of the Karroo fauna, *Lystrosaurus*, *Dicynodon*, and *Chasmatosaurus* from the lower zone, *Sinokannemeyeria* from the upper middle, and saurischians and *Bienotherium* from the Upper Triassic, show that China is likely to prove one of the centres of continental life.

3. Formerly only the Lower and Upper Cretaceous vertebrate faunas were known in Outer Mongolia, Suiyuan and Charhar. They are chiefly characterized by various dinosaurs. Southwards, however, Upper Jurassic dinosaurs are better represented. As for the fishes, *Lepitodus* should be considered one of the most characteristic forms. Recently, Rhynchocephalia and Lacertilia have also become known from the Upper Jurassic of China.

4. The Early Tertiary fauna of China is very rich, although it is mainly restricted to the Eo-Oligocene time. The content of the fauna shows not only affinities to those of Europe but also to those of North America as well. I shall not go into the details of this matter, but it should be sufficient to say for my present purpose that Asia was once the centre of the development of mammalian life in the world.

5. The Pliocene fauna is characterized by the abundance of *Hipparion*, and this fauna represents actually the eastern extension of the Pontian of Europe. Nevertheless, it must be noted that there must have been a special faunal interchange between Africa and China, as is clearly revealed by the Cavicornia. It is certain also that North China was situated on the main road of faunal exchange between Europe and Africa on one side and North America on the other.

6. As is well known, the uppermost Pliocene fauna is considered the equivalent of the Villafranchian of Europe. The rich lower Pleistocene of China reveals also affinities to other parts of the world. The "thick jawed" deer (*Sinomegaceros*), for example, is even recorded in Algeria. It is interesting to note that instead of an east to west interchange of fauna, as was the case during Pontian times, the Plio-Pleistocene of China is characterized by the north-south direction of interchange. This sort of vertebrate migration was so intensive that it overshadowed that of the other direction, if that had not entirely ceased.

IV. CORRELATION WITH THE FAUNA OF OTHER CONTINENTS

Most of the main horizons of vertebrate remains can easily be correlated with those of the other continents, at least in a general way. This has already been done in preceding sections, but several points may be discussed here:—

1. The pre-Jurassic vertebrates in China are so poorly known that it is difficult to draw any reliable conclusion as to the development of each group. Take, for instance, the Lower Triassic fauna: China may merely represent one of the off-shoots of the Karroo fauna so well known in South Africa, but it might possibly prove to be the other way round should the fauna of China be better known. This possibility may also be applicable to the faunas of the other horizons.

2. In many instances the faunal boundary lines between the Jurassic and Cretaceous, and between Pliocene and Pleistocene, raise some difficulties. Either the sediments are continuous without break, or there are some faunal difficulties in making a satisfactory separation. There are many points which cannot be settled before the faunas of each horizon become better represented and thoroughly studied.

3. Generally speaking, there is no difficulty in a general comparison and correlation of the faunas between China and other parts of the world, provided the leading and characteristic forms are known. Some doubts, however, arise as to the lateral shifting of time. The *Bothriolepis* beds in China, for example, have been regarded by some Chinese geologists as somewhat earlier than those of the European standard based upon stratigraphical and invertebrate evidences.

4. The standard for correlating geological age by means of fossil plants and invertebrates is sometimes different from that of vertebrates. It is to be regretted that in many cases in China the plants and invertebrates associated with fossil vertebrates have not yet been properly studied. Therefore a final correlation table is still unattainable.

V. LITHOLOGICAL FEATURES AND CRUSTAL MOVEMENTS IN CONNECTION WITH THE VERTEBRATE HORIZONS

(See Table)

The chief lithological characters are given in the fourth column of the Table and the main periods of crustal movements or disturbances are indicated in the fifth column. It becomes evident that

MAIN VERTEBRATE HORIZONS AND GEOLOGICAL EVENTS

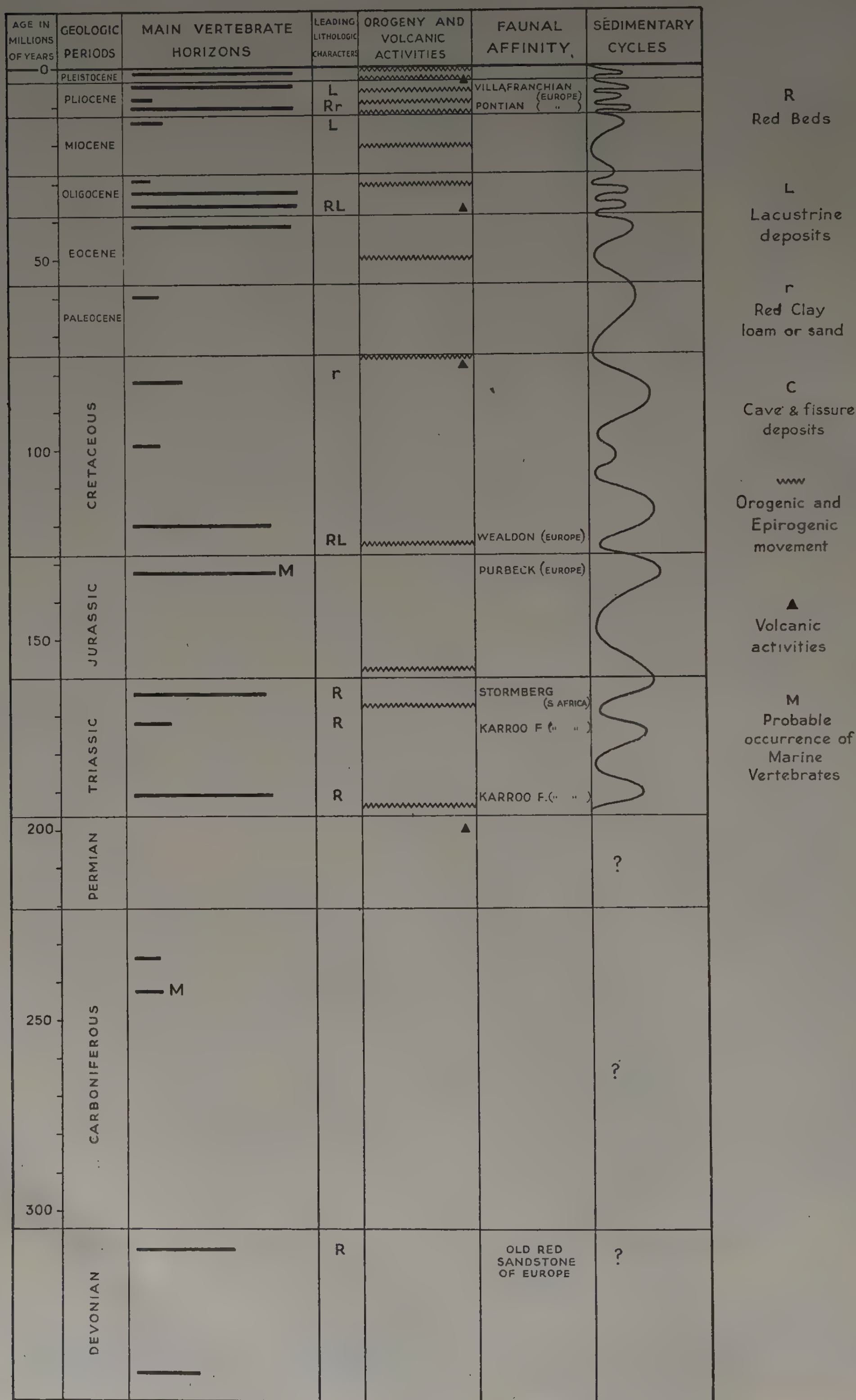

FIG. 2.

most, if not all, of these fossiliferous horizons simply represent more or less coarse sediments caused by rejuvenation or uplifting or movement. This is especially clear in Cenozoic times where a cycle of sedimentation is usually followed by a cycle of erosion as the consequence of a disturbance. It is also obvious that most of the fossiliferous beds are red beds or red clays, only a few being of lacustrine or fluvial nature.

Looking at the six main vertebrate levels makes it clear that there are certain large gaps due to the absence or scarcity of vertebrate fossils. They are: Carboniferous-Permian gap, Middle Triassic gap, Lower Jurassic gap, Upper Cretaceous and early Palaeogene gap, Lower Eocene gap, Upper Oligocene and Lower Miocene gap, and Middle Pliocene gap. Although many of those gaps are consequences of crustal movement, there are also those due to lack of systematic research. This is especially true in Carboniferous-Permian time in which the coal seams, sandstones, and shaly sediments are quite abundant and likely to be rich in fossils; in fact, plants and invertebrate remains are well known. Why there is no record of vertebrate life in the era is puzzling.

Another fact must be noticed: that the present description of vertebrate fossils is devoted exclusively to land or lacustrine forms. Marine vertebrates are lacking except for some faint indication of their presence, and are marked as " M " in the third column of the Table.

When we think that before the Republic of 1911, fossil vertebrates were known only through the hands of druggists, we must admit that we have made considerable progress. The present knowledge of vertebrate life in China should be regarded as a milestone for further research.

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PRINCIPLES IN CORRELATION AND THEIR APPLICATION TO LATER CENOZOIC HOLARCTIC CONTINENTAL MAMMALIAN FAUNAS

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U.S.A.

ABSTRACT

The inception of Burdigalian time in Europe and of Hemingfordian in North America initiated intermittent intercontinental dispersals between Eurasia and North America which have continued until Recent time. It appears that representatives of the different groups of mammals reached the adjacent continental areas at different times and the dispersals are evenly distributed during the time under discussion. There is no evidence of mass migration between the hemispheres. The author believes that paleontologists agree in their correlation but disagree in their concepts. He believes that the long-established epoch terminology for the Cenozoic should be retained but the law of priority should be rigidly applied in the use of names.

It is intended here again to direct attention to some evidence on mammalian evolution and distribution as a means of determining the synchrony of faunal and geological events within the Holarctic region in Miocene and Pliocene times. It has been emphasized elsewhere (Pilgrim and Hopwood, 1938; Stirton, 1939) that there have been wide dispersals of mammalian genera between continental land masses without appreciable evolutionary changes taking place. With the accumulation of evidence on faunal sequences in different parts of the Holarctic region and with more information on the evolution in certain groups, our correlation of the faunas has become more refined. Consequently there is now little disagreement on the Age level in correlation in the two hemispheres. In other words contemporaneity within the time limits of an Age is usually readily recognized—only those faunas falling near the time boundaries are seriously questioned.

On the other hand many opinions are held on the inclusion or exclusion of some of these faunas in one or another of the stages in our time-stratigraphic terminology or in different epochs.* Most of these difficulties arise from the fact that Lyell's (1833) original time-rock units, together with the units of later authors, do not represent all of Cenozoic time. This kind of difficulty is to be expected in the developmental processes in any given field of science. It would seem logical, then, with our increased knowledge, that arbitrary time boundaries could be agreed upon in the epoch boundary problems. One of the chief difficulties encountered is due to the fact that the type sections of Lyell's "periods," as with most of the European stages, are based on marine sections and their contained faunas. These marine faunas must be correlated with European continental mammalian faunas (and this appears to be the weakest link in our chain of evidence) which in turn can be synchronized with the North American and Eurasian fossil mammalian faunas, but the correlations of the marine rocks and faunas with the fossil mammalian faunas on that continent are necessarily based on current opinions of those familiar with the field evidence. Here, too, I have found confusing conflicts. It would seem, therefore, that this particular phase of the problem could stand some careful reinvestigation.

The considerations above indicate rather clearly that accurate correlations must be founded on definite concepts. The concepts suggested here are—following Kleinpell (1949)—"(1) typology; (2) general principles of paleontologic correlation; (3) particulars of specifically pertinent correlation—

*For stratigraphic terminology see Schenck and Muller (1941).

well disciplined chronologies founded upon controlled biostratigraphic sequences." Deviation from typology in the principles of Cenozoic correlation has already brought about considerable disagreement in correlation, and unless corrected, is likely to end in nomenclatorial chaos. I have referred to the application of criteria furnished by such phenomena as orogeny and glaciation, or the sudden appearance of immigrant genera in neighbouring continental masses. Diastrophism has admittedly long since lost its front rank standing in the principles of correlation. Everyone, of course, is aware of the significance of epirogenic disturbances throughout the world, the evidence for which is frequently relied upon by the stratigrapher especially when fossils are not available. Nevertheless it is sometimes quite alarming to see field geologists still employing the evidence of local orogenies far beyond the sphere of usefulness of these orogenies in epoch correlations. Geologic time is no respecter of our arbitrary terminology; and in certain instances the boundaries, even the all important era ones, have been demonstrated to fall within the limits of one formation (Gazin, 1941).

Other geologists and paleontologists continue to wield the cudgel of glaciation upon Lyell's type Pliocene thus reverting to Edward Forbes's (1846) usage in considering the initiation of glaciation as the inception of Pleistocene time.* Contrary to the law of priority, Pliocene (Lyell's Older Pliocene) would then become a synonym of early Pleistocene. On the other hand these same scientists evidently use typology or orogeny, or both, as their keys to other Cenozoic epochs. Here, too, the geographical distribution of terrestrial mammals is frequently introduced in support of certain epoch boundary proposals, *e.g.*, *Hyracotherium*—Lower Eocene; *Anchitherium*—Lower Miocene; *Hipparion*—Lower Pliocene; *Equus*—Lower Pleistocene. There is no doubting the usefulness of such evolutionary and dispersal data in establishing the relative contemporaneity of widely separated faunas; but such evidence cannot be expected to coincide with designated type sections, local orogenies, marine transgressions or recessions or glaciation, though in certain cases and in given areas it may do so. The difficulties to be encountered in employing such a complicated system are readily demonstrated in the fate of the Sub-Apennine type Pliocene strata. It would seem quite obvious that consistency in the interpretation of evidence will necessitate the use of related concepts only.

The law of priority as a principle of nomenclature is often referred to in geologic literature, but it has never become the useful tool that it has in biology, nor has it been so rigidly applied. The boundary controversies on each of the Cenozoic epochs seem to indicate clearly that profitable application of this system could be made in the earth sciences. As stated above and as shown in the chart, the original time-rock (=time-stratigraphic) units do not include all Cenozoic time. It had been tentatively suggested that these intervals be set aside as other stages and ages to be referred to as Oligo-Miocene, Mio-Pliocene, etc., but this will likely only burden us with additional boundaries to rankle over. The early systematist in biology did not have all of the species under observation, nor did he know the ultimate scope of the genus he was proposing on one or a few specimens; but through the years additions and corrections governed by related concepts under the laws of biological nomenclature are producing an orderly arrangement.† It is recommended that, to attain simplification and accuracy in correlation, we follow the concepts outlined above by Kleinpell (1948) and strictly adhere to the law of priority.

If, then, we apply the law of priority in geologic time terminology we should make every effort to determine which rock units were used by the original author in his type designations and the "concept (the concept in its true historic context) he had in mind in doing so." (Kleinpell, April 4, 1949 oral communication.) The type time-stratigraphic units with which we are most concerned here are those employed by Lyell for his Miocene, Older Pliocene (Pliocene) and New Pliocene (Pleistocene).

Most authors who have discussed epoch correlation problems have paid little or no attention to

*This was even adopted by Lyell in 1873, but at that time he did not realize that some of the first glacial advances were contemporary with the time-stratigraphic units of his type Older Pliocene.

†This is true even though Linnaeus held different ideas on the relationships of plants and animals in the lower categories from those currently in use.

these type areas, but have spent most of their efforts in marshalling orogenic, glacial or animal distributional evidence in support of their conclusions. It is quite clear that Lyell designated the Superga Hill near Turin as the type of his Miocene. These are marine beds and were correlated with faunas of the same age in the Bordeaux basin. It would seem logical, then, that at least the time represented by these rocks and their contained fauna or faunas should be included in the Miocene. Since continental beds do not interdigitate with the marine beds in the type area, the correlations with mammalian faunas were made primarily in the Bordeaux basin where the marine equivalents of the Superga beds offer evidence of synchrony with land-laid formations and faunas. The Bordeaux beds, in turn, have been correlated throughout the Holarctic region on the basis of faunal evolution and dispersal. At present most mammalian paleontologists consider the European mammalian faunas ranging from the Montabuzard (Burdigalian) to the La Grive-Saint-Alban (Vindobonian) as equivalent to the type Miocene.

From the point of view of a vertebrate paleontologist, the type of the Pliocene offers, in one respect, somewhat more direct evidence; and yet, in another respect, is more difficult to interpret. There are vertebrate faunas (Casino and Val D'Arno) within the area of the Sub-Apennine hills of northern Italy, the area that was designated by Lyell as the type of his Older Pliocene. It could be argued, and has, that Lyell did not necessarily include these vertebrate faunas in his type which was based primarily on marine strata and fossils. He did, however, include the Val D'Arno in his discussion and would have included it in his Pliocene except for the mistaken notion that it was considerably older (pp. 220–221). He quite clearly did not consider it as younger—to quote—" and we are therefore disposed to believe that they belong to an older epoch," p. 220. Furthermore he discusses it under the heading " Miocene Fresh-water Formations." The Casino fauna was not known to him, but it possibly occurs in the lower part of the beds mentioned by him in the discussion of his Older Pliocene. Lyell described blue clays (=Casino + Plaisancian) overlain by yellow sand (=Astian + Calabrian) under the title " Older Pliocene Formations." Pilgrim (1938; 1940) and others have directed attention to the close relationship of the Val D'Arno to the Astian, part of Lyell's marine type, and Pilgrim (1938, pp. 443–446) has emphasized evidence for considering the Roussillon and the Montpellier faunas as existing very close to Villafranchian time. Since it seems quite obvious that the Val D'Arno mammalian faunas are not of the same age as the marine Superga, and since they occur in the area and in rocks contemporary with those discussed by him in his description of the Older Pliocene, I have always concluded that they properly belonged in that epoch. This is supported further by Gignoux (1913, p. 308) who cites evidence for the presence of *Elephas meridionalis* Nesti and *Equus stenonis* Cocchi from both the upper Val D'Arno (= Calabrian = upper Astian) and the lower Val D'Arno (= lower Astian). If these occurrences are true it would seem that there is very little if any faunal difference in the continental equivalents of the marine stages Astian and Calabrian, and these marine faunas may represent near contemporaneous assemblages but different facies. This would indicate that the Roussillon and Montpellier are much nearer to the Plaisancian in time than Depéret (1890) thought possible.

As near as can be determined from the descriptions in his book and from the near Recent age of the fossils used in Lyell's lists, his Pleistocene (Newer Pliocene) is later than even the continental deposits in the Val D'Arno. Gignoux (1913, pp. 283–285, and elsewhere) considers his Calabrian and the Villafranchian to be the equivalent of Lyell's Newer Pliocene. If this is true the time-stratigraphic units of the Pleistocene occur in both the type sections of the Pliocene (Older Pliocene) and of the Pleistocene (Newer Pliocene). It is difficult to understand why Lyell and his assistants did not recognize " Newer Pliocene " fossils in the Plaisance region (part of type Pliocene area), particularly in collections of Signor Bonelli at Turin (Lyell, 1833, p. 61) if they are as well represented there as indicated by Gignoux. For these reasons I have not favoured the placement of the Val D'Arno (both upper and lower) in the Pleistocene even though its faunas were well populated with *Equus stenonis* and *Elephas meridionalis* and though contemporary faunas are correlated with the inception of glaciation elsewhere.

The boundary between the Miocene and the Pliocene is quite another problem. If our ideas about the upper limit of the type Miocene have been correct, considerable time is represented between that and the basal limit which the most ardent glaciologist would allow for the type Pleistocene. I have followed the concepts of Merriam (1919, p. 454), and Matthew (1929) in considering the first appearance of *Hipparion* as a suitable marker for the beginning of the Pliocene. This I assume would include the most primitive species (an undescribed species) here in the Orinda of California. Recently, however, M. Crusafont Pairó and J. Truyols Santonja (1947) have directed attention to the presence of *Hipparion* in Spain where it is associated with other mammals identified by them as being conspecific with those in the Sansan, Elgg, Goriach, La Grive-Saint-Alban and their equivalents. They, therefore, assign this fauna in Spain to the Vindobonian and place it in the Miocene. This is an important correlation but this formation and fauna should be synchronized with the marine beds at Superga Hill. If it is Miocene, the Clarendonian also is Miocene, and if the Pontian is Miocene, as some writers suggest, most of our Hemphillian is Miocene. This leaves very little in the Pliocene and essentially nothing if the Villafranchian is Pleistocene.

My recommendations for a correlation of Miocene, Pliocene, and Pleistocene formations and faunas within the Holarctic region are graphically expressed in the accompanying chart (p. 82), unless it is proven that *Hipparion* evolved from *Merychippus* before the sedimentary rocks at Superga were deposited.

MIOCENE AGES AND STAGES

Arikareean.—Studies on the evolutionary progression and on faunal differentiation in the known assemblages, though not as complete as one would like, indicate that as much or more time is represented in the Arikareean than in either the Hemingfordian or the Barstovian. The middle and upper John Day, Tecuya, Gehring, upper Martin Canyon, lower Rosebud and Monroe Creek are typical of the early faunas of this Age though more refinement in the relative ages of these faunas can be made with careful critical comparisons. These faunas are generally considered to be the correlatives of those assigned to the Aquitanian* of Europe as typified by the Saint Gerand-le-Puy, Pyrimont, Laugnac, Weisenau, Celles-sur-Cher and Laussane. This intercontinental correlation was previously supported by the supposed presence of the beaver *Steneofiber* in both regions. Later investigations, however, have shown that the North American species are referable to the genus *Palaeocastor*. Evidently these beavers are not closely related but possibly have evolved independently from an unknown Lower Oligocene common ancestry. I am convinced that Kaup's original type of *Palaeomys castoroides* did come from beds of Aquitanian age, possibly Weisenau; though I now feel that *P. castoroides* is not synonymous with his *Chalicomys jaegeri* from Eppelsheim. The rhinoceros *Diceratherium* was another genus used in Saint Gerand-le-Puy-John Day correlations; but this genus is now restricted to the New World and, as I understand, the European species are now referred to the genus *Aceratherium*.

There are ten genera listed from the Aquitanian assemblages that also occur in North America; but they are either long ranging and slow evolving genera or have representatives in earlier or later Ages. Two of the genera which may be helpful in this correlation are the bear-dog *Amphicyon* and the tree-squirrel *Sciurus*. There are records of *Sciurus chalaniati* Pomel from the Upper Oligocene faunas, Peublanc and Coderet; but I have not seen the specimens nor can I vouch for their identification. The two species from the John Day, *S. wortmani* Cope and *S. bollovianus* Cope, and *S. tecuyensis* Bryant from the Tecuya of California have been carefully restudied by Dr. M. D. Bryant (1945). He

*J. Wyatt Durham (1944) in a discussion of the type section of the Aquitanian has directed attention to information that " the type locality of the Aquitanian Stage is not in the vicinity of Bordeaux, France, but in the vicinity of Papplemont, Courtemantruy, Plainmont-Dessous, and Courgenay, in north-west Switzerland "—Valley of Ajoie. This Aquitanian, according to Durham's citations, was assigned to the Oligocene by Mayers in 1858. It is also stated that a correlation of the type Aquitanian at Ajoie with the Aquitanian in the Bordeaux basin has not been established; the type may be equivalent to the Chattian of Germany. If the type of the Aquitanian is at Ajoie, and if those beds are of the same age as the type Chattian, the Saint Gerand-le-Puy and its equivalents either belong to another Age or the so-called later Stampian mammalian assemblages, *e.g.*, Peublanc and Coderet, are incorrectly assigned to the Chattian.

concluded that they were referable to the genus *Sciurus*. European specimens, however, were not available to Bryant so the relationships of the Aquitanian species *S. feignauxi* Pomel and *S. chalaniati* Pomel to the North American species are not adequately understood.

The same situation is more or less true in reference to *Amphicyon*. Several suggestions have been made on the phylogenetic relationships of the Amphicyoninae; none of which is very convincing. The North American Lower to Middle Oligocene *Daphoenus* is the most likely ancestral genus. It could have given rise to the Whitneyan and Arikareean *Temnocyon* and to the late Arikareean *Daphoenodon* in the New World, also to "*Amphicyon*" *lemanensis* Pomel, *A. crassidens* Pomel, and to other early Miocene and late Oligocene species in the Old World. *A. crassidens* seems more closely related to the Middle and Upper Miocene species of *Amphicyon* both in America and Eurasia than does either *Daphoenodon* or "*A.*" *lemanensis*. One of the last two is probably ancestral to *Pliocyon*.

Loomis (1932) has described one species of *Pachycynodon* from the lower Rosebud and another from the upper Harrison, but their direct relationship to the Old World genus is still questionable. *Pachycynodon* was described from the Phosphorites of Quercy (Stampian), and is supposed to occur in the Lower Oligocene of Asia. The American species seem to have a bicuspid heel on M_1.

The equid genus *Anchitherium* is not as useful in a precise correlation of the North American faunas with those in Eurasia as was previously supposed; although a critical revision of the species may reveal some useful information. The genus evolved from *Miohippus* at the close of the Whitneyan or early Arikareean. The known metapodials from Arikareean species tend to be long and slender. A representative of the genus did not reach Europe until Burdigalian time; and this species, *A. aurelianense* (Cuvier), is not as large in dental measurements, according to Mayet (1908), as *A. praestans* Cope from the John Day. Such size differences are not always reliable as progressive characters. The metapodials of this earliest *Anchitherium* from Europe are not known, but one from the Vindobonian fauna at Sansan is heavier and shorter than the American species. Similar differences are displayed, however, in contemporary species of *Hipparion* from the Old World. On the whole, then, *Anchitherium* does not seem to offer adequate evidence for close correlations.

Cook and Cook (1933) have indicated that the lower Harrison, lower Rosebud and the upper Harrison* faunas are more advanced than those from the early Arikareean assemblages. More recent evidence seems to support the contention of Cook and Cook (1933) that these faunas are all different in age but only slightly so. Unfortunately for convenience in correlation, the upper Harrison and its equivalents have been included in the type Hemingfordian. The first species of *Merychippus*, then, are not indicative of the beginning of Middle Miocene time in North America. In America we have assumed that the lower Harrison, upper Rosebud, upper Harrison, Marsland and at least part of the Sheep Creek were the equivalent of the Burdigalian, though the upper Harrison and the Marsland offer evidence for the most direct correlation. This is based on a beaver in the American faunas which appears to be closely related to the so-called "*Steneofiber*" *depereti* Mayet. Evidently the ancestry of this important beaver is from one of the John Day or lower Rosebud palaeocastors. The lower Harrison and upper Rosebud may belong opposite the late Aquitanian or this particular time may not be represented in the European mammalian sequence.

The differences in the specimens from the two hemispheres, then, do not support terrestrial connections between the continental masses in early Arikareean and Aquitanian time. The correlation of these faunas is supported by the intercontinental dispersals that took place with the introduction of the Burdigalian assemblages.

Hemingfordian.—The beginning of the Burdigalian in Europe not only shows an evolutionary progression in certain Aquitanian species, but also is marked by the first occurrence of "*Steneofiber*"

*"The Marsland fauna is intermediate between those of the 'Upper Harrison' and Sheep Creek. It is characterized by *Aletomeryx* and especially by the first appearance of *Merychippus*, which is absent from the 'Upper Harrison' fauna." Cook and Gregory (1941). Schultz (1938), and Lugn (1939) on the other hand have considered the upper Harrison and Marsland faunas as equivalent. Some more recent evidence tends to support the interpretation of Cook and Gregory.

depereti, *Hemicyon*, *Pseudaelurus*, *Miomastodon*, *Turicius*, *Gomphotherium*, *Anchitherium*, and *Chalicotherium*.

The beaver and *Anchitherium* had their origin in North America. The immediate ancestors of *Pseudaelurus* and *Hemicyon* are not known. *Chalicotherium* probably came from an Asiatic ancestry. Some fragmentary remains of a chalicothere in the Phillips Ranch (probably the same age as Marsland) in California may or may not be related to the Burdigalian species, and we are not yet certain of the generic identity of Barstovian remains. The proboscideans may have come into Europe from Africa or south-western Asia.

Miomastodon depereti Osborn from the Burdigalian of Chevilly, according to Osborn, is more primitive than *M. merriami* Osborn from the Virgin Valley and *M. matthewi* Osborn from Pawnee Creek. In so far as I know *M. merriami* marks the first appearance of the proboscideans in the Americas. The pattern of the cheek-teeth indicates that the genus is more closely related to the Burdigalian *Turicius* than to the gomphotherines (trilophodont mastodons). Possibly both *Miomastodon* and *Turicius* were derived from some south-western Asiatic or north African species. True *Amphicyon* is found in the Sheep Creek. Evidently this genus came into America shortly before *Miomastodon* which has not been found in the large Sheep Creek fauna nor in the Thomas Farm assemblage.

The upper time limit of the Hemingfordian was not sharply designated as a time-stratigraphic unit by Wood and committee (1941). There may or may not be a time gap between the upper limit of the Hemingford group and the Barstow formation which are the type time-stratigraphic units of the provincial ages. Numerous faunas, which almost completely intergrade, are represented in these Ages. For example, the Virgin Valley and the High Rock Canyon are closely related; but the High Rock Canyon has certain species of *Merychippus* and *Tomarctus*, yet unknown in the Virgin Valley, that are as advanced as some in the Barstow. Perhaps the High Rock Canyon is Hemingfordian, but this cannot be accurately determined until we know something of the faunas from the upper part of the Hemingford group as this stratigraphic unit was defined by Lugn (1939). Many other near contemporary faunas to these throughout the United States pose similar problems in correlation.

The beginning of Burdigalian and the beginning of Hemingfordian are probably very close to contemporaneity, but the Hemingfordian was longer and may have partly overlapped the Vindobonian.

Barstovian.—The Barstovian is exemplified by the Mascall, Niobrara River and interspersed faunas which are roughly the equivalents of the Sansan and the La Grive-Saint-Alban. *Hemicyon*, with its first records in the Burdigalian, occurs in both the Vindobonian and Barstovian. The beaver *Amblycastor* has been recorded from the Tun Gur of Mongolia and the Barstovian, though there is a possibility that certain specimens from Texas may belong to a Hemingfordian assemblage. *Ursavus*, which is not uncommon in the Vindobonian, is known in America from only one specimen of questionable identity in the Pawnee Creek of Colorado. The *Pseudaelurus* specimens from the Vindobonian and Barstovian are very much alike. The similarity in these species was early recognized by Leidy (1869), Depéret (1887) and others. The sabre-tooth cat *Sansanosmilus* is of unusual interest; it seems to possess characters that should place it in the ancestry of *Machairodus*. *Sansanosmilus* did not reach North America, though *Machairodus* did but much later and in the Pliocene. The other two genera useful in correlating the Vindobonian with the Barstovian are *Gomphotherium* and *Serridentinus*. *Gomphotherium* was present in the Burdigalian, continued into the Vindobonian, and makes its first North American appearance in the Mascall. This genus ranges into the Pliocene in both hemispheres. The relationship of typical *Rhynchotherium* to *Gomphotherium* is not clearly understood. The canid genus *Aelurodon*, common in the late Barstovian, also occurs in the Tun Gur of Mongolia. *Platybelodon* from the same fauna probably reached North America in Pliocene time.

The intercontinental dispersals are represented by more genera in the Upper than in the Middle Miocene, but our present evidence tends to indicate that the times of dispersals were pretty evenly spread throughout these two Ages.

PLIOCENE AGES AND STAGES

Clarendonian.—As stated previously the Sarmatian and Pontian are the controversial Stages in Mio-Pliocene correlation. There is as yet no clear indication of the amount of time represented in the type time-stratigraphic units of these two Stages, and the age relationship of the Sarmato-Pontian mammalian faunas is still a controversial problem. It is quite clear, though, they are not represented in Lyell's type units. Perhaps the placing of them in either the Miocene or the Pliocene is not so important, but it is significant that the continental faunas assigned to them do represent considerable time. In reading Merriam's (1919) and Matthew's (1929) correlations, it should be borne in mind that they are based on the assumption that the faunas now included in the Clarendonian and Hemphillian represented the same Age as the so-called *Hipparion* faunas in Eurasia. They did not differentiate between the two Ages in America. But it now seems clear that the Clarendonian is older than the Eppelsheim, Pikermi, Samos, Dhok Pathan and related faunas and younger than the La Grive-Saint-Alban.

It is questionable whether the Orinda fauna, early Clarendonian, and its equivalents on the Pacific Coast of North America have a known correlative in Eurasia. If such has been found in the Old World, it is not adequately known. There has recently come to light in the Orinda and its equivalent the most primitive species of *Hipparion** yet known. It is slightly more advanced than the most progressive species of *Merychippus* in that line of descent yet more primitive than those in the Chinji or Siesta and Ricardo. Unfortunately the Orinda fauna is not sufficiently known in the other groups of mammals to throw additional light on this correlation. The Burge of the Great Plains is useful in this respect, but is not as closely related as the Pacific Coast assemblages. In India this time may be represented by the unconformity between the Chinji and the Kamlial. When the stratigraphic positions of the *Hipparion* faunas in China have been carefully worked out in vertical sections, it may be found that some of these are contemporary with the Orinda. This could be true of certain European assemblages that are still in need of detailed description. A Siesta *Hipparion* and some other specimens on the Pacific Coast are very much like those from the Chinji. Those in the upper Ricardo beds and the teeth from the Rattlesnake compare most favourably with some of the early Pontian species.

Other genera which may assist in clearing this correlation are *Pseudaelurus*, *Amphicyon*, *Hypohippus*, ?*Sansanosmilus*, *Eomellivora*, *Gomphotherium*, and *Serridentinus*; but we need to learn more on the phylogenetic relationships of their species.

Hemphillian.—The faunas ranging in age from the Rattlesnake to the Thousand Creek " may be correlated very nearly with the Pontian," Pilgrim (1940, p. 23). I reached this same conclusion independently and discussed it with Pilgrim in correspondence. Perhaps our best correlations can be made with the faunas in India where there is good stratigraphic control. The Nagri fauna, according to Pilgrim, seems to be a little more closely related to the Chinji than to the Dhok Pathan. The American equivalent may be in part Clarendonian and in part Hemphillian. In other words, it seems slightly older than the Rattlesnake, Mulholland, Kern River, and Higgins. Some of the most useful genera in establishing a Hemphillian-Pontian correlation are *Dipoides*, *Indarctos*, *Agriotherium*, *Eomellivora*, *Plesiogulo*, *Machairodus*, certain species of *Hipparion*, etc. The broader relationships of these faunas have been discussed at length by Osborn (1910), Matthew (1924, 1929), Pilgrim (1940), Pilgrim and Hopwood (1938), Teilhard de Chardin and Stirton (1934), Stirton (1936, 1939), Colbert (1935, 1942), and others.

The castorodine beavers which are so well represented in the Barstovian of North America by the genus *Monosaulax* gave rise to *Eucastor*† in the Clarendonian and this in turn to *Dipoides* in the Hemphillian. Species of *Dipoides* reached Eurasia in Pontian time; the latest and most progressive species is *D. sigmodus* (Gervais) in the Montpellier fauna (Astian in accordance with the correlations

*This species will be described in the near future.

†I believe the beaver described from China by Teilhard de Chardin (1942) as *Eucastor stirtoni* is more closely related to the ancestry of *Trogontherium* than to *Eucastor* and *Dipoides*.

of Depéret and Pilgrim). This clearly establishes the faunas in which this genus occurs as not being older than Hemphillian.

Indarctos, *Eomellivora* and *Plesiogulo*, in so far as the records are now known, are confined to the Hemphillian and Pontian. The sabre-tooth cat *Machairodus*, evidently a descendant of *Sansanosmilus*, is common in the Hemphillian and plentiful in the Pontian of China. In North America it ranged into the Blancan; but in the Old World it gave rise to *Epimachairodus* in the Astian and Villafranchian and their equivalents. *Agriotherium*, common in the Hemphillian, has been recorded from the Pontian and continued into the Tatrot, Pinjor, and Montpellier.

Blancan.—One of the most significant gaps in our knowledge of the Cenozoic record in North America is that between the Hemphillian and the Blancan. This time in Eurasia may be represented by the Casino, Roussillon, Montpellier, Perrier, Tatrot, and closely related faunas. Perhaps the best evidence for a correlation of the Blancan with the Astian-Villafranchian of the Old World is the occurrence of *Mimomys*, *Castor*, *Canis*, *Ursus*, *Equus*, *Cervus*, and possibly *Chasmaporthetes* which may be related to *Lycaena*.

Castor, evidently derived from the Pontian *Chalicomys*, reached North America in abundance in the Blancan. The microtine *Mimomys* which is restricted to the Blancan in North America ranges from the Villafranchian into the early Pleistocene in Europe. *Canis* makes its first appearance in these Upper Pliocene faunas in both hemispheres and on both continental areas and continues to Recent time. *Ursus* evidently arose from an Old World Pontian species of *Ursavus* and was already present in the Roussillon fauna. The genus reached America in Blancan time and is still extant on both continents.

It has been demonstrated that *Equus* (horses, zebras, and asses) probably arose from late Hemphillian species of the genus *Pliohippus* now referred to the subgenus *Astrohippus*. It has not yet been adequately demonstrated that different species of this subgenus gave rise to two groups of *Equus*; the horses and asses representing one group and the zebras the other. As McGrew has pointed out, the American Blancan species clearly possess zebra characters as do most of the Old World Pliocene specimens. One of the earliest records of true *Equus* is *E. quaggoides* Major from the Val D'Arno of northern Italy. If this group arose from a different species of *Astrohippus* than that which gave rise to the zebras, where are they in numerous Upper Pliocene faunas that have been recorded in both the New and Old Worlds? Perhaps the explanation may be found in a northern Asiatic assemblage not yet known. Possibly the zebras are the more primitive of the two groups, and it was after these animals had spread into the Old World in Upper Pliocene time that one of their species gave rise to the asses and the horses. Representatives of this group then spread back to North America during the first interglacial; but by that time all of the zebra-like animals had become extinct here, or nearly so. *Equus*, in the broad sense, is not known in Europe from the Casino, Roussillon, Montpellier, Perrier, and their equivalents, though Lewis has mentioned teeth from the Tatrot of India. Unfortunately these teeth have not been figured or described. The zebra-like horses, then, in the Blancan, Pinjor, Sanmenian, and Villafranchian offer good evidence for the correlation of these Ages.

Cervus is first recorded from the Pontian, but came into North America first in Blancan time; in the Old World, of course, it continued on through to Recent time. The hyaenid *Chasmaporthetes* from Texas and Arizona seems most closely related to *Lycaena*. It may be useful in correlation when its relationships are better understood and more specimens have been found.

There is little doubt that the Blancan is the time equivalent of the Villafranchian, Sanmenian, and Pinjor.

SUMMARY

The inception of Burdigalian time in Europe and of the Hemingfordian in North America initiated intermittent intercontinental dispersals between Eurasia and North America which have continued until Recent time. On the basis of our present knowledge it appears that representatives of the different groups of mammals reached the adjacent continental areas at different times. These dispersals are

LATER CENOZOIC HOLARCTIC VERTEBRATE CORRELATION CHART

	NORTH AMERICA	CHINA & MONGOLIA	INDIA & BURMA	EUROPE
	Rancho La Brea *Irvington*	*Choukoutien*	Boulder Conglomerate	*Eringsdorf* *Tegelen*
PLIOCENE*	*BLANCAN*	Nihowan	Pinjor Tatrot	VILLAFRANCHIAN ASTIAN PLAISANCIAN
	HEMPHILLIAN	Ertemte	Dhok Pathan	PONTIAN
	CLARENDONIAN	(Hipparion Faunas)	Nagri Chungi	SARMATIAN
		?		?
MIOCENE*	BARSTOVIAN	Tun Gur-Shanwang	Kamlial	VINDOBONIAN
	HEMINGFORDIAN	Loh	Fatehjang	BURDIGALIAN
				?
	ARIKAREEAN			AQUITANIAN

* Lyell's time-stratigraphic units

FIG. 1.

pretty evenly spread throughout the duration of the time mentioned above. There is no evidence of mass faunal migrations between the two hemispheres.

In conclusion, I should like to reiterate that most vertebrate paleontologists agree, for the most part, on the correlation of their faunas, but they disagree on the concepts to be employed in these correlations. Consequently the names Pliocene, Miocene, etc., have become almost meaningless. This was one of the main reasons why a committee on Nomenclature and Correlation of the North American Continental Tertiary (Wood, 1941) was formed which resulted in the Provincial Ages now in use on this continent. There are many reasons why we should continue to use the long established epoch terminology for the Cenozoic; and irrespective of recent trends to the contrary, those names will be applied. Nevertheless I believe we can have a useful terminology if we rigidly apply the law of priority followed by the basic concepts of correlation.

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SOME CONSIDERATIONS AFFECTING THE MIOCENE-PLIOCENE BOUNDARY QUESTION IN VERTEBRATE-BEARING ROCKS IN NORTH AMERICA AND EURASIA

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ABSTRACT

The author postulates a temporary land bridge that allowed mass migration to North America of mammals whose original home probably became submerged, and outlines paleogeographical and physical changes that are directly related to the problems of intercontinental migration of vertebrates. He makes a plea for the evaluation of paleontological with the geological evidence.

No monophyletic key is of satisfactory use.

For the relevant boundary question he regards the Nebraska-Kansas-South Dakota area as a critical one.

In his paper, *The Application of the European Time Scale to the Upper Tertiary of North America*, Guy E. Pilgrim has clearly presented a summary of published evidence by leading scientists and, in particular, has drawn interesting and incisive conclusions concerning many of the inherent problems involved, with both paleontological and paleogeographical data in mind. Because of the complexity of many of these problems and incomplete evidence with which to deal, there are, in frequent instances, differences of opinion which may readily disappear when more complete facts have been ascertained, while other facets of the problem may remain much more difficult to solve.

Obviously the problem of intercontinental zoologic relationships among vertebrates, which have admittedly migrated and intermigrated over long and tortuous routes during extended periods of time, is so intimately related to the problem of past climatic and changing physiographic conditions that all contributing factors should be known and considered simultaneously in order to maintain proper perspective, and thus to be sure that any conclusions reached are the result of mature consideration from every angle.

For example, it is possible that, when we have more complete knowledge in order to evaluate the geological evidence concerning the possible " dual origin " of such groups as *Hipparion* (so ably discussed by Pilgrim and others), a different approach as to analogies or homologies may be indicated. Let us consider some indirect evidence at this point.

In spite of the current dominance of opinion, based on geophysics and other evidence, that existing continental masses and oceans have long had comparable relationships, including many well-known variations throughout geological time, it appears to me that there is also evidence, commonly not cited, which does tend to indicate the distinct possibility of the presence, in the geological past, of one or more continental masses which could have served either as a centre of origin, development and dispersal, or a land bridge, while above water. To be specific, where was the area located on which the large and diversified pre-Paleocene mammalian fauna was developed?—a fauna which apparently reached North America suddenly at the close of Lance times in the Paleocene and early Eocene as well developed races. These early Tertiary mammals were certainly well differentiated, many groups being fully established and suggesting a long evolutionary history, before suddenly appearing here. With a few exceptions the fauna has no close relationship to any other known in the older fossil-bearing beds that immediately precede them. It seems highly improbable that the ancestors of most of these distinctive types, apparently unrelated to any others known from the Lance or any other Cretaceous or older beds, could have existed on any now known continental area, without some trace of them

being discovered in such fossiliferous deposits. It appears that the more simple and probable answer is that, as a result of marked diastrophic and orogenic activity, well known to have taken place during the Laramide Revolution—then in being—a temporary (perhaps intermittent) land bridge may have permitted mass migration of such a large fauna to areas of North America where they are now found, and perhaps their original home may have been completely submerged, since no one has yet found an upper Cretaceous fauna from which most of the Paleocene and Eocene mammalian faunas could have been derived.

Comparably, it can be noted that in many places in the higher mountains of both North America and Eurasia, marine Cretaceous (and later) beds are now elevated as much as several thousand feet above sea level. In line with isostatic considerations, it is logical to argue that, if old sea-bottom deposits of Cretaceous age can be raised in great masses thousands of feet above current sea-level, why may not comparable masses have been submerged as much below that level, at the same time, consequently being as concealed to fossil collectors of to-day as the old, sea-bottom deposits are now available? Recent deep core drilling in some of the Pacific islands has disclosed the presence of previously unknown, thick, Tertiary deposits of unknown extent, beneath present sea-level. This is thought-provoking. If it is possible to reach and study such beds, over a wide area, such data may considerably modify some currently held ideas.

Further, I have seen remains of *Elephas* cf. *imperator* on Santa Barbara Island, some twenty-odd miles off the California coast, with water more than a mile deep now separating this chain of islands (an old, submerged coastal range) from the mainland. This provides rather clean-cut evidence that movement of such magnitude must have occurred in that area in late Pleistocene times. As elephants are not sea-going mammals, and as *Elephas* admittedly did not reach North America before Pleistocene times, this is an interesting occurrence. Since this region is part of the old zone of weakness and marked diastrophism which extends along the western coast of South and North America past Alaska and the eastern edge of Asia, it seems logical to assume that movements, up or down, may have occurred at various times elsewhere along the same zone. A very minor fraction of the rising-falling movement indicated along the California coast could easily have made, or broken, the land connections between Alaska and Asia. This may have been of such a mild order as to have left little evidence of such emergence or subsidence—perhaps relatively few feet, in Tertiary times—so that it is not necessary to assume that migrations could have occurred only when great masses of sea water were " land-locked " in Pleistocene glaciation through this area, for such a land connection to be present, either in Pleistocene times or earlier. That we have evidence of vertebrate intermigrations between North America and Asia in late Miocene and Pliocene (or earlier) times, when there was no such glaciation, tends to bear this out.

While these in part theoretical considerations may seem far afield, at first glance, from the question of the Miocene-Pliocene boundary problem, they are here introduced because of their application to some phases of this problem.

Bearing on this matter, one rather important factor which has, apparently, often been missed by American geologists, and which inevitably had a marked influence on vertebrate migration, was the occurence, in mid-Tertiary times in North America, of a period of pronounced orogenic activity which C. J. Hares and I have named the " Rocky Revolution." This was not merely a part of the Laramide Revolution, as some have interpreted certain observed evidence of Miocene diastrophism. It came about after a long interval of quiescence in the region, that extended throughout most of Paleocene, Eocene, and Oligocene times. The Rocky Revolution was initiated at the close of White River, Oligocene times; developed in intensity in Lower Miocene times and continued intermittently into the Pliocene, with diminishing activity at the close of the Pliocene; and into Pleistocene times. There is some evidence that this activity may not yet be terminated. The evidence of this activity in the Rocky Mountain region and adjoining plains areas is under study by the writer and others. Particularly clean-cut, it is, fortunately, well preserved, especially in Wyoming and adjoining regions, where the effects of such orogenic and epirogenic movement on master streams, and their relation to

folding, faulting, and the origin and deposition of sediments, with accompanying rapid changes in climatic conditions, flora and fauna, offer endless problems that have, as yet, been meagerly studied and little understood. This is largely due to the fact that some of such evidence has rested unrecognized, while other material at hand was under study; also that several sorts of specialists should be co-operating on all phases of the problem, which has, as yet, merely been touched upon.

Obviously, then, it is necessary to know more about these activities and about the paleogeographic and climatic conditions that affected the ancient mammalian migration routes.

In 1928, W. K. Gregory and the writer noted, in studies on the genus *Trigonias* from northern Colorado, evidence which we interpreted as indicating probable hybridism between races of rhinoceros that had probably come from the same ancestry, but presumably had been separated, geographically, for a considerable lapse of time and developed somewhat differently. Then, through changed physical conditions, when they converged and interbred, an astonishing divergence of characters was produced in a contemporaneous fauna. It is difficult to postulate any other adequate cause for the diverse characters that we noted. Characters observed in this assemblage were obviously ancestral to characters noted in described species, from beds immediately succeeding in the geological series. If our interpretation of the evidence noted in that group is correct, it may offer a suggestion as to the answer to some problems concerning the horses and other groups used in considering intercontinental correlations.

When considering the geological evidence we see a noteworthy progression of events, in mid-to-late Tertiary times, in the Rocky Mountain region and its environs, in North America. Oligocene times, largely represented by the White River series of beds, were widely characterized by deposits indicating generally low elevations and low gradients, with fine clays, silts, and volcanic dust predominating. These had been deposited and bedded chiefly by water with little current, and contained some intermittent stream channel deposits of coarser sand or gravel, the latter increasing in prevalence toward older mountain areas.

With the close of Oligocene times, as represented by upper phases of the White River, and with the advent of Miocene times (the Gering-Monroe Creek-Harrison sequence) we note the tendency to deposit progressively coarser materials, indicating an increase in gradient away from the Rocky Mountains, to the eastward. Comparably, and correlating with this, we note in certain areas, distinct structural and stratigraphic breaks between each of these phases, and a distinct change in the origin and distribution of sediments. With these are marked and progressive changes in fauna with some interesting problems of habitat introduced. At the close of Arikareean times gradients had increased, and in some critical areas structural deformation had progressed to where it had a distinct influence on Tertiary master streams.

These Miocene beds are primarily flood-plain deposits, and a number of changes occurred, evidently involving migration and readjustment in advancing fauna, on which little has been published to date.

Immediately following Arikareean times, in the zone represented by eastern Wyoming and western Nebraska, east of the Rocky Mountains, the Miocene structural deformations involved, as well as the increased elevations, contributed to the first marked period of erosion in late Tertiary times, with well-developed mid-to-late Miocene stream channels eroded out, and then refilled, in later Miocene or Pliocene times. With the close of the Miocene and opening of the Pliocene, more marked elevation of the mountains occurred to the westward, with evidence of distinct increase of gradients widely indicated by the increase in the average size of sediments to coarse sands and gravels, in this zone, and by the inception of widespread erosion and surface channeling. By late Pliocene times, in this area, where an unusually full record is preserved for study, erosion had gained the ascendancy over sedimentation and deposition, and modern stream drainage systems were well initiated. These were developed throughout Pleistocene times. In some cases, as in the North Platte valley, they re-cut as much as a thousand feet.

Eastward of the zone of deformation here discussed, where gradients decreased, much of the distinctive geological evidence here noted is obscured or absent. Fortunately most of these beds are

rich in finely preserved fossils, which permit fine paleontologic correlations. Unfortunately, however, much of this correlation has been done, to date, with far less attention given to the parallel geological evidence available, than it deserved. As a result, there has been a marked paucity, until very recently, of published literature bearing on several interesting problems here involved.

When Hares and Cook presented the first report of the Rocky Revolution before the Geological Society of America in 1936, the comment was made at that time that the literature was almost barren of specific illustrations of deformation and differences in elevation involving the late Tertiary beds in or near the Rocky Mountains. Unfortunately, little of this rather abundant evidence has, as yet, been recorded in print. At that time Hares and Cook noted a fault zone, with pronounced block faulting, involving the Miocene beds, and with a maximum throw in excess of 700 feet, running easterly from the front ranges of the Rocky Mountains, in the vicinity of Wheatland, Wyoming, and past Fort Laramie and into north-western Nebraska. Elevation of Oligocene and Miocene (and Pliocene, in some cases) beds then studied, gave definite evidence of deformation up to several thousand feet, in and near the mountains. In northern Colorado; in various areas across Wyoming, to the north; in the Medicine Bow, Laramie and other mountains and along the continental divide; as well as in the zone or belt bordering these mountains, there is a wealth of evidence of such early Miocene, mid-Miocene, late-Miocene, and post-Miocene distortion, with folding and dips up to 48 degrees or more, noted; extensive block faulting and various other types of faulting being present, in addition to a great deal of other evidence.

Further, there is much information contained in the logs of oil wells and in geophysical surveys but, unfortunately, because of their commercial aspect, most of these data are not available for publication at this time and have been but little studied, to date, by any geologist or paleontologist interested in any but their commercial side. Both Hares and I have been privileged to examine much of this subsurface and geophysical material but, of course, the evidence it contains cannot be published at present.

Eventually, when available for research and publication, such subsurface data will greatly enrich the literature, and increase our understanding and improve our interpretation of numerous problems.

This is not the time and place to present a detailed discussion of the Rocky Revolution, but because it is so little known and so little material has, as yet, been published concerning it; and because of its application to the problem in hand, it seems desirable to call attention to it briefly here, and to point out the character of available evidence bearing upon it—as yet largely unpublished. Because of the presence of movements accompanying uplift in the Rocky Mountains in late to post-Miocene time, the resultant topographic, climatic and other changes certainly had some profound effects on habitat, migration routes, natural barriers and other related factors, in the areas where such movements occurred. At present there is but little indication in the literature that many of these factors have been studied or understood. It is,as yet, an almost virgin field for research, in some of its aspects.

To the west of the Rocky Mountains I have noted, as far as Arizona and California, evidence that appears to tie in closely with the study of the Rocky Revolution; and I do not doubt that its activity extended far to the northward, also that it ties in with comparable activity in Asia, producing profound paleogeographical and physical changes that are directly related to the problem of intercontinental migration of vertebrates.

It is my purpose here to emphasize the need for more extended study with these diverse elements in mind and not limited to the correlation based on physical characters in vertebrates alone, though these are, admittedly, the most important criteria in many cases.

As the mountains were undoubtedly much higher and more abrupt in mid-Miocene to post-Miocene times than now, and in many instances unquestionably more difficult to traverse for most quadrupeds, it is entirely understandable that relatively temporary barriers, yet of considerable duration, could have directed and controlled migration to a high degree. It is apparent that these could have persisted long enough to permit considerable isolated, independent development in any group confined to a relatively restricted habitat, so that, by the time such barriers were removed by subsequent erosion

and such groups reunited, the divergent modifications developed would, with interbreeding, tend to break up characters, produce hybridism, and add to the complexity of the paleontologist's problems. This possibility is one Gregory and I considered carefully in our studies on the genus *Trigonias*.

Affecting the Miocene-Pliocene boundary correlation question, and long neglected and still unsolved, to a large degree, are a number of existing conditions with which the Rocky Revolution is directly concerned. For example, there is the fact of the occurrence of gravels on some of the high mountains of the inter-major-stream and continental divides, at least some of which are demonstrably Pliocene in age. Where did these come from—how did they get there? Great deformations and overthrust faults, such as Heart Mountain, Uinta and Lewis, exist. It will require study to time them accurately and to interpret, with proper perspective, the paradoxical stream courses of such rivers as the Wind River, Shoshoni, the Platte and the Laramie, that apparently performed the impossible—unless the late Tertiary history of deformation and mountain building is interpreted in the light of greater activity, during the time of the Rocky Revolution, than has generally been assumed, and with resulting effects extending into the Great Plains and other regions.

When attempting the correlation of physical data with paleontological evidence, it would seem important to try, when possible, to do this with particular attention to those areas where the sharpest and most definite structural and stratigraphic breaks occur, simultaneously with fossils, rather than in regions where elisions of depositional boundaries and "fuzzy" contacts exist, with consequent incomplete evidence. Paleontological correlations alone, from isolated basins or local deposits, where corroborative physical data are not present, tend to be incomplete, and this can be particularly true when one bears in mind the differences that can arise from isolation caused by natural barriers. This is especially true among vertebrates highly sensitive to a rapidly changing environment in their responses and adaptations—as, for example, the horse—long used as a paleontological correlation key by specialists in that field.

While we have long valued those vertebrates which responded most actively to a rapidly changing climate and related physical environment, as keys for correlation, rather than invertebrates, plants or aquatic vertebrates such as fish, whose changes and responses were either less rapid or less easily determined, in short geological sequences, by their fossil remains, it is obvious that, because of this very rapid adaptation to active environmental changes it behoves us to evaluate the paleontological records of such vertebrates with particular care and with clear perspective on surrounding geological evidence and not on osteological data alone. Admittedly difficult, this seems necessary. If the evidence from a typical area is unusually rich and diverse, it can best serve to give us needed keys, with a better perspective.

In the eastern Wyoming and western Nebraska section, and nearby areas, direct structural and stratigraphic evidence is available, with which to correlate included fossils, thus dating these beds and stratigraphic breaks to an unusually accurate degree, particularly in the Miocene, and to correlate with Rocky Revolution data elsewhere. In the later Miocene-Pliocene succession (Sheep Creek-Snake Creek) an unusually full record exists but unfortunately it is so complicated and involved, and the early collecting and recording were so inexact, that the picture is confused, rather than clarified. I am one of those guilty for this condition being true, as I made, with W. D. Matthew, the original discovery of these beds, and reported them with him. I can freely say that we did not at first, or for a long subsequent period, know of this complexity or comprehend many of the facts and factors we now know, and did not realize the critical necessity here for exact mapping, unusually careful observation of depositional data in these highly complicated and interlaced deposits, as well as precise recording of the occurrence of all fossils. This can still be done by collectors with the proper training and understanding of the problem in hand, and sufficiently equipped with the means to carry it out.

While it is true that extensive collecting has been done in these beds, the surface has barely been scratched. The rather abrupt break or change in sediments that occurs here, between the cemented, finer grained beds of the late Miocene Sheep Creek deposits, and the generally uncemented or poorly cemented, Pliocene Snake Creek beds, takes place, fortunately, at about the probable boundary

between the Miocene and Pliocene in most places. There are marked exceptions to this as at Spoon Buttes, for example, on the Wyoming-Nebraska border, west of the type locality of the Snake Creek beds, where the sharp sands and mountain gravels of the Pliocene Snake Creek beds are cemented into a very hard, coarse sandstone, resistant to erosion; and to the eastward and south of the type locality, in Nebraska and Kansas, where more general cementing occurred in the Pliocene in the form commonly called " mortar beds." There is a noticeable tendency, particularly in the Pliocene beds, for sediments to overlap progressively, becoming finer grained and spreading out more to the eastward, indicating decreasing gradients, away from the mountains.

It is noteworthy that, with the advent of these coarse mountain gravel and sand deposits, which correlated with rapid elevation of mountain areas westward—up-drainage—there also occurred the sudden appearance of many Eurasian types of mammals as migrants, including old-world forms such as *Neotragoceros*, rhinoceros of probable Asiatic origin and relationships such as *Mesoceros thomsoni*, and others cited in the well-known faunal lists from these beds. This is indicative of the wide-flung activity at this time, affecting migration. Early Proboscideans, which first reached North America in or about mid-Miocene times, suddenly occur in great diversity in the opening of the Pliocene, undoubtedly arriving via Asia and Alaska, with the abundant warm-temperate to sub-tropic flora and fauna of the early Pliocene. They are a part of an exceptionally full and rich fauna, only part of which is, as yet, described. It may be logically inferred that suddenly changed physical and geographical conditions had permitted and facilitated these abrupt intercontinental migrations. Such conditions were apparently established about mid-Miocene times, on the basis of the evidence furnished by the first appearance of Proboscideans.

The beds of Pliocene age, in the typical zone here principally under discussion, were first deposited on the finer sediments of the Miocene Sheep Creek, valley-fill beds, next distributed over a very wide area by a widely meandering master stream, ancestral to the present North Platte River; then cut, filled and recut in some areas in a complex manner, until the gradient so increased that, by later Pliocene times, erosion gained the ascendancy over deposition and the period of great valley cutting, previously mentioned, was inaugurated. Structural warping that correlates with mountain elevating, westward, took a hand at directing and altering the courses of such master streams and their deposits in many cases with considerable rapidity, so that the Pliocene was a period of rapid changes, involving physiographic factors and climate; all of which was intimately tied in with the later activity of the Rocky Revolution in this country, and with the related and synchronized activity northward and in Asia, in a manner that requires wide perspective in obtaining and evaluating evidence.

The excellent and comprehensive report on the *Nomenclature and Correlation of the North American Continental Tertiary* by the outstanding committee headed by H. E. Wood, gave a very accurate picture of the current understanding of the relationships in these beds. Naturally, as is to be expected, some differences of opinion exist, and new evidence is bound to cause some modification of present opinions. As indicated, adequate and comprehensive studies are still lacking, or are unpublished, bearing on some of the Miocene and Pliocene problems, where material is available to do much more exact work than has been done. This should be done with consideration for all available evidence of every sort that may apply to the problem at hand, and not with the limited perspective of a single field of research.

Some of the more recently published studies have been approaching the problems suggested here, in part, from divergent viewpoints. Atwood and Atwood have called attention to some of the high-level boulder conglomerates and gravels as well as widespread uplift in the Rocky Mountains in late Tertiary time, in their paper just published. But, evidently, they were not familiar with the dating evidence indicating that this revolution was initiated considerably before the time they postulate, namely, about the close of Pliocene times; and that some of the data to which they refer are susceptible to other interpretations than those which they make.

The principles recorded in recent observations by McGrew, indicating differences in contemporary faunas because of difference in climatic gradients in widely separate areas, at a time when the warm

Pliocene was cooling off (the initial stages when the chilling Pleistocene was being inaugurated) are equally true, with variation to fit the physical conditions, of the rapid faunal changes that occurred near the Miocene-Pliocene contact.

I concur with the statement of Schultz and Stout, when they say, "It appears certain that the Pliocene-Pleistocene boundary dispute, in common, perhaps, with the Oligocene-Miocene and Miocene-Pliocene boundary controversies, can be more nearly solved in the Nebraska-Kansas-South Dakota region than anywhere else in America." In this they are following and coincide closely with conclusions I had stated long before they had begun research; many of their conclusions closely following results I had obtained years ago. However, as previously indicated herein, fine and diagnostic as this evidence is, it yet needs much broader study that considers the evidence of other areas and related geological events connected with the Rocky Revolution in North America, and with contemporaneous and comparable orogenic and epirogenic activity in Eurasia, in order to possess perspective in evaluating clearly some of the complex, detailed phylogenetic and correlation problems which have been so ably discussed by so many workers. Anything like a comprehensive review of this detailed evidence would require more time and space than is available for this paper, and such data are available in published reports.

Hibbard has made valuable original observations on the late Pliocene-Pleistocene paleophysiography east of the Rocky Mountains that fits in closely with data I have observed there, and he has stressed the part played by some early rivers. While I fully appreciate the fact that it would be far simpler if we could arbitrarily accept specific faunal forms or diastrophic events or climatic phases as Miocene-Pliocene boundary designators, yet, because of the paleophysiographic, biotic, and climatic variables to be considered in intercontinental correlations, there does not appear to be any monophyletic key of satisfactory universal application to the various areas involved in this problem; and only by a symposium of specialists in various related fields and by more adequate and comprehensive studies, can close regional determinations be satisfactorily made.

Independently, and with Charles J. Hares, research geologist for the Ohio Oil Company, I have been at work intermittently for many years on some of the evidence bearing on the Rocky Revolution, and its relationships to the problems of intercontinental correlation of Tertiary faunas, with exceptional emphasis on Miocene-Pliocene-Pleistocene aspects. We hope to have some of this material ready for publication soon. Admittedly, the wide-flung and diverse character of the problem to be solved here will consume much time and require the painstaking work of many specialists, in order to proceed beyond the point already reached in the published literature and present contributions.

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LABYRINTHODONTS FROM THE TRIASSIC MOENKOPI FORMATION OF NORTHERN ARIZONA

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THE CHINLE FORMATION OF NORTHERN ARIZONA AND NEW MEXICO AND ITS FAUNA

By E. H. COLBERT
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In these two talks, illustrated by coloured lantern slides, the speakers gave accounts of recent expeditions they had made in these respective fields. They discussed the fossil vertebrate remains they had found, though in both cases detailed results were not yet available. A short discussion followed in which:

T. S. WESTOLL said that the beautiful slides shown by Dr. Welles and Dr. Colbert aroused a feeling of envy in those whose work was in the New Red Sandstones of Britain. Here we had no such magnificent and extensive exposures, and could only guess at the possibilities of collecting if our strata were as well exposed.

Dr. Welles had very properly told us something of the tetrapod fossils, which were clearly of great importance. It seemed, from personal conversation, that there were also coelacanths and lungfishes in the Moenkopi, and also in some other Triassic Red Beds. It was to be hoped that further collecting might allow the nature of the fish-faunas to be clearly established; we required much new information about the Triassic lungfishes in particular. The existence of an *Aphaneramma*-like stegocephalian recalled the reports of *Birgeria* from the Triassic of California; the existence of other members of the Spitsbergen fauna, if it could be established, would be of great paleogeographical significance.

D. M. S. WATSON pointed out that the great importance of the Moenkopi fauna was that this continental series of rocks passed laterally into marine rocks whose age in the normal marine series was known. The extreme abundance of Labyrinthodonts in these beds recalled the conditions in Russia and stood in sharp contrast with the Karroo conditions.

In later times there was complete absence in South Africa of the Phytosaurs which were much the most abundant reptiles in beds of the same age in Germany and especially in North America.

The urgent need of a thorough study of the conditions under which vertebrate-bearing continental deposits were laid down was emphasized.

LIST OF THE PARTS OF THE REPORT OF THE EIGHTEENTH SESSION